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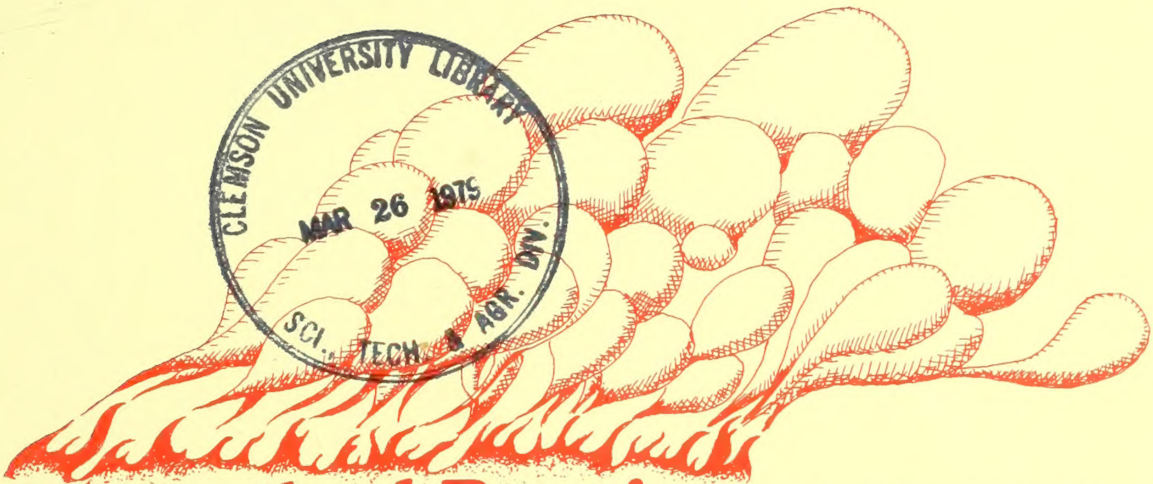

anning for Prescribed Burning in the Inland Northwest

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PRESCRIBED BURNING. "Skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture, etc. that will allow confinement of the fire to a predetermined area and at the same time will produce the intensity of heat and rate of spread required to accomplish certain planned benefits to one or more objectives of silviculture, wildlife management, grazing, hazard reduction, etc. Its objective is to employ fire scientifically to realize maximum net benefits at minimum damage and acceptable cost" (Society of American Foresters 1958).

Successful prescribed burning depends on:

SKILLFUL APPLICATION of fire from a
CAREFUL PRESCRIPTION developed for a
DEFINITE AREA to accomplish
SPECIFIC OBJECTIVES.

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Foreword

We prepared this report to help managers and others understand the effects of fire and how to use fire in managing forests and rangelands. The literature cited in the fire effects section is limited for readability; however, we list many publications in the "Additional References" section for more information. Publications, such as "Environmental Effects of Forest Residues Management in the Pacific Northwest" (Cramer 1974) and "Fire and Ecosystems" (Kozlowski and Ahlgren 1974) have extensive literature citations.

The reader may wish to read about fire effects and potential uses of fire or to use it in planning a specific burn. The second and third sections deal with uses and effects. For planning purposes, the sections "Planning the Prescribed Burn" and "Sample Burning Situation" should be helpful.

Abstract

Fire has historically played a role in forests and ranges of the inland Northwest. This guide has been prepared to help managers understand the role of fire and the potential uses of fire and to plan for fire use in managing these lands. Sections deal with these topics, and steps in planning a prescribed burn are outlined. A sample burning situation illustrates the planning and execution of a prescribed burn. References are given to help the reader locate pertinent information.

KEYWORDS: Fire use, fire effects, fire planning, fire management, prescribed burning.

Contents

Introduction

PURPOSE AND OBJECTIVES

The purpose of these guidelines is to aid forest and range managers in eastern Oregon and Washington to understand more completely the key elements of planning and using prescribed fire as a management tool. Specifically, these guidelines are designed to provide the land manager with:

1. Information on possible uses for prescribed fire.
2. Information on some basic effects and impacts of wildfire and prescribed fire on forest and range ecosystems.
3. A practical reference for planning and executing prescribed burning operations, including methods and techniques.
4. Guidelines for evaluating burns to determine effectiveness in meeting prescribed objectives and to gain information for future planning.

Information is presented on potential uses for prescribed burning in the inland Northwest, effects of fire, planning for prescribed burning, and prescription parameters. A sample burning situation and other aids to prescribed burning are at the end of the paper.

FIRE HISTORY AND ECOLOGY IN THE INLAND NORTHWEST

Fire is a natural force in the development of forest and range ecosystems. It has played an important role in eastern Oregon and Washington, and attempts to exclude it from this area have frequently altered the vegetation to a less favorable condition. Even with the efforts of organized fire control, we have not been completely successful in excluding fire and, on occasion, have allowed a buildup of fuel so that wildfires became large and destructive. Controlling catastrophic fires is hazardous and extremely expensive.

In attempting to exclude fire from east-side forest and range ecosystems, man has been running contrary to a natural succession which established and maintained those systems. In doing so, we have allowed a significant accumulation of dead organic matter that does not decay rapidly in the cool, dry climate of eastern Oregon and Washington.

Today, forest and range managers are beginning to realize that fire, if managed properly, can actually help maintain vegetation in a condition that is more ecologically stable, as well as more pleasing and useful to man. By using fire judiciously, we can work with the natural system more economically and rationally--rather than trying to force the system into unusual patterns.

The frequency and severity of natural fires in eastern Oregon and Washington vary considerably with location because of the marked differences in climate and vegetation, which can range from alpine to desert. Our best record of prehistoric fire comes from scarred tree trunks. Many other fires undoubtedly occurred but were too low in intensity to leave any trace. Early travelers in this area described the ponderosa pine[1/] forests as parklike and open to travel, presumably as a result of frequent low-intensity fires.

[1/] Scientific names not given in the text will be found in table 2, page 12.

The frequency of fire scars in ponderosa pine forests in this region varies from 6 years (Soeriaatmadja 1966) to 47 years (Weaver 1959, 1961); most often, somewhere between these extremes. Although we do not know how many of the prehistoric fires were started by Indians or lightning, we do know that lightning starts an average of 21 to 40 fires per million acres each year in this region (Schroeder and Buck 1970). Historically, fire periodicity in open rangeland may also have varied considerably. In the wetter sage-grass sites, Martin and Johnson[2/] think fires occurred from 5 to 15 years apart. In the drier sage-grass types, fire may be much less frequent.

The role of fire in ecosystems is quite varied, depending on the successional stage of the system, condition of the vegetation and fuels, and nature and frequency of fires. If the classical concept of vegetative succession is used, plant communities move from the pioneer or early vegetation stage through the seral or intermediate vegetation stage to climax vegetation, which will remain on the site unless a disturbance occurs. If severe disturbances such as fire, insects, disease, or windthrow occur, succession is usually retarded or moved back toward earlier stages. Moderate disturbances, such as frequent light fires, may advance, back up, or merely hold succession at a given stage (Martin et al. 1976). For example, a moderate fire may thin a stagnated ponderosa pine stand and move it forward toward a climax condition such as a mature ponderosa pine-bitterbrush community. On the other hand, a potential grand fir (*Abies grandis* (Dougl.) Lindl.) site may, through repeated low-intensity fires, remain in ponderosa pine.

Frequent periodic fires maintain forest fuel hazards at a low level. Weaver (1967) describes how prescribed underburning has reestablished this condition in some managed east-side ponderosa pine stands where it has been applied repeatedly over a period of years. Hall (1976), in a study of fire ecology in the Blue Mountains of eastern Oregon, pointed out that fire exclusion is causing ponderosa pine to be replaced by white fir (*Abies concolor* (Gord. & Glend.) Lindl.) or Douglas-fir, gradually changing the plant community from fire resistant to fire susceptible. He emphasized the important role that prescribed fire can play in reducing fire hazard, improving soil conditions for pine growth, providing control of stocking level, and increasing forage and browse for livestock and wildlife.

Today, population pressures, particularly in the urban/wildland interface, greatly influence the practicality of natural fire. Protection of life, property, and resources are paramount issues with fire protection agencies. Yet, carefully prescribed fires can be useful tools in helping to reduce high intensity wildfires and potential losses.

Dell (1976) described several new directions foresters are exploring today in applied fire use on National Forests in the inland Northwest. He discussed recent studies of prescribed fire designed for timber stand improvement, treatment of understory vegetation and slash from logging and thinning, and range and wildlife habitat improvement.

[2/] Martin, Robert E., and Arlen H. Johnson. 1978. Fire management of Lava Beds National Monument. *In* Proceedings 1st Conference on Research in the National Parks. NSF-NPS, New Orleans, Nov. 1976.

Potential Uses of Prescribed Burning in the Inland Northwest

The forest or range manager develops objectives for the units of land being managed. With these objectives in mind, the manager looks at the available ways in which they can be met. Decisions to use fire or other tools would logically proceed from land management objectives to the tools to be used and thence to the specific treatment objectives.

Any prescribed burn may have more than one objective. By coordinating efforts among various resource personnel, the manager may accomplish two or more objectives with one burn. As an example, burning of thinning slash will reduce fire hazard, increase accessibility for livestock and wildlife, and perhaps improve tree growth through nutrient release and reduction of plant competition. Esthetics and human access may be improved by the same fire.

HAZARD REDUCTION

One of the most obvious uses of prescribed burning is to reduce the vegetative material produced by forests and ranges. This material ignites readily when dry. Under adverse weather conditions, the dead material and much live vegetation can result in a very destructive wildfire that is difficult to control. Reduction of the fuels under moderate burning conditions reduces the possibility of conflagration in that area for a time.

We do not have substantial data for the rate of fuel accumulation in the inland Northwest. Consumption of slash from logging in this area, however, should require only one prescribed burn in most cases. Prescribed burning under most ponderosa pine stands every 5 to 15 years should keep natural fuels at an acceptable level. The frequency of burning, as well as the conditions and season of burning, will vary, depending on the objectives of the manager for a particular area (fig. 1). Reduction of hazard is often most crucial in thinning or logging slash. To date we have made little use of fire in reducing thinning slash, but there is great potential as there are many thousands of acres of untreated or partially treated thinning slash in the region. Fire can be used to reduce the hazard (fig. 2).

SILVICULTURE

There are several ways in which prescribed burning can be used to accomplish silvicultural objectives, such as site preparation, vegetation manipulation, and insect and disease control.

Site preparation.--Regeneration of timber stands requires preparation of the site for natural regeneration, seeding, or planting. The site may require treatment because of slash accumulations, shrubs or grasses, or heavy duff (fig. 3). Fire can be used in these cases. In the brush field, the treatment prescription may call for an herbicide or desiccating chemical in combination with fire.[3/]

[3/] All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended. Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Figure 1.--Hazard reduction was a principal objective in this burn along a heavily used recreation highway. Esthetics of the area was also improved.

Figure 2.--Fire is being used here to reduce thinning slash. The prescription called for cool weather and light wind at a time when the larger fuels were too moist to burn.

Figure 3.--Site preparation was accomplished by this prescribed slash burn in clearcut slash, where both the slash and heavy duff would hinder planting. Fire hazard was also greatly reduced.

Species manipulation.--Different frequencies, intensities, and seasons of fires will favor different plant communities on any given site. Relatively frequent, low-intensity fires may favor ponderosa pine (fig. 4); less frequent, intense fires may favor the prolific lodgepole pine; whereas, without fire or other disturbance, succession on inland forests may lead to a stand of Douglas-fir, true fir, or incense-cedar. By prescribed fire we might also reduce stocking of any species to provide optimum growing space. After setting realistic goals for any piece of land, we can prescribe fire to help meet many of these goals.

Figure 4.--A low-intensity fire was used in this ponderosa pine stand to remove a dense understory of incense-cedar. Reduction of shrub competition and fire hazard was a secondary objective accomplished with the burn.

DISEASE AND INSECT CONTROL

Insects, disease, and fire are all interrelated. Fire has been instrumental in controlling some diseases, such as dwarf mistletoe (*Arceuthobium campylopodum* Engel.) (Alexander and Hawksworth 1975). Apparently the parasite spread rapidly after effective fire control was developed. Prescribed fire has been used to burn diseased slash and heavily infected regeneration so that a healthy new stand could develop. Research underway is designed to test use of fire in reducing mistletoe infestation in released ponderosa pine. Critical information is lacking on the relationship of fire to other important tree diseases in this area.

Fire and insects are closely related. Fire often creates insect problems. For example, fire-damaged trees are vulnerable to bark beetle attack, and insects may increase fire hazard by increasing the supply of dead fuel. Prescribed fire, properly applied, may control insects directly or reduce their damage through indirect means. At certain stages in an insect's life cycle that are sensitive to fire, we can achieve direct control. For insects dependent on a certain habitat condition which fire can remove, such as duff accumulation or the presence of fire-sensitive host species, we can achieve indirect control through prescribed burning. For example, the proportion of true fir in a mixed stand could be reduced by prescribed burning; this would reduce the risk of losses to the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) (fig. 5).

Figure 5.--Prescribed burning was used in this case to impede development of fir in a ponderosa pine stand. The research burn was conducted because circumstantial evidence indicates that many warmer, dry fir habitats should be held in pine to reduce Douglas-fir tussock moth susceptibility.

WILDLIFE HABITAT MANAGEMENT

Fire is well known for its contributions to habitat improvement for many wildlife species, notably large mammals and birds. Generally, fire will favor some species of wildlife, whereas lack of fire might favor others. When the mixture of wildlife that is most desirable on an area is decided, the land manager can develop a prescribed burning program to meet the objectives. With low-intensity prescribed burning, old decadent stands of wildlife browse species may be regenerated or caused to resprout, providing palatable and nutritious food for game. Examples are bitterbrush, mountainmahogany, and several species of ceanothus. High elevation meadows, now being invaded by tree species, can be maintained by prescribed burning (fig. 6). Livestock and wildlife could have access to areas now inaccessible because

Fig. 6.--This high elevation meadow is slowly being invaded by subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Fire could be used to maintain the meadow for wildlife.

of thickets or dead and down trees. Forage and browse could simultaneously be improved by prescribed burning, at the same time leaving escape and thermal cover for wildlife. By developing a mosaic of prescribed burns, no burns, and burns of

different sizes, intensities, and periodicity, we provide for various needs of different wildlife. Wildfires did this in the past, as they burned intensely at one time and crept gently along at another, often leaving vegetative islands completely untouched.

RANGE MANAGEMENT

Fire has been important in producing more palatable and nutritious forage for domestic livestock, whether in timbered or open range. Much original bunchgrass range in this region is now dominated by juniper, sagebrush, and other woody species, probably as a result of overgrazing and fire suppression. Prescribed burning, possibly aided by chemical or mechanical treatment and seeding, can be used to rejuvenate desirable grasses. Once range is reconditioned and properly grazed, fire alone may be used to maintain a satisfactory condition (fig. 7).

Figure 7.--Fire rejuventated native grasses in the foreground, juniper and sagebrush dominate the vegetative complex in the background.

ESTHETICS, RECREATION, AND ACCESS

A forest managed with fire is often much more pleasing to look at, provides more opportunities for recreation, and allows better access. Frequent, low-intensity wildfires generally kept the ponderosa pine forests of the region open and parklike, where early pioneers could "let their horses take their heads." In contrast, many of these same forests today are choked with shrubs or stagnated thickets of reproduction because of fire exclusion (fig. 8). Reintroduction of fire can reduce the shrubs and thickets, recreate parklike vistas, provide more space for recreation, and create access for man and animals. When a forest is reconditioned by prescribed burning, there may be a 1- to 3-year period when scorching or char can detract from esthetics.

Figure 8.--This ponderosa pine stand once provided open vistas and ready access. Fire exclusion has permitted dense white fir thickets to form. Wildfire, once started, would destroy the entire stand, including the once-fire-resistant ponderosa.

Fire Effects

When considering the use of fire as a tool in forest and range management, one must inevitably ask the question, "What are the effects of fire--on living and dead plant materials, on animals, on soil and nutrients, and on water and air?" We will present a brief account of these effects.

BASICS OF COMBUSTION

A forest and range fire rapidly oxidizes the organic materials produced by living plants. Much the same process occurs over long periods of time through various decomposing organisms. Completely combusted fuel yields about 8,600 British thermal units (Btu) per pound or 20 000 kilojoules (kJ) per kilogram (kg). It is this heat that is primarily responsible for damaging or killing plants. We will discuss the effects of heat later. In practical land management situations, we know that many fuels are not burned at all and others are incompletely burned; only about 6,000 Btu/lb (14 000 kJ/kg) are available from burning. The results of incomplete burning are residual fuel, smoke, and carbon monoxide; the effects on air are covered later.

FUEL CONSUMPTION

Fuel consumed by a fire is the source of energy output. The amount to be consumed on any prescribed burn can be modified by the prescription set by the fire manager (table 1) Slash burning in the Northwest generally consumes from 50 percent to over 90 percent of the fuels less than 3 inches (7.62 cm) in diameter (fig. 9);

Table 1--*Fuel consumption of prescribed burning under ponderosa pine and Douglas-fir stands*[1]

Fuel portion	Loading before fire	Moisture content	Fuel consumed	Source
	Tons/acre[2]	- - - Percent - - -		
Ponderosa pine:				
Duff layers--				
L and F	--	8.0 to 8.6	--	
L, F, and H	10 to 17	--	70 to 73	Davis et al. 1968
H	--	17 to 26	--	
Douglas-fir:				
0-0.25 inch (0-0.64 cm)	1.6	12 to 17	82	
0.25-1 inch (0.64-2.54 cm)	2.3	13 to 16	67	
1-3 inches (2.54-7.63 cm)	5.0	12	41	Swanson 1974
>3 inches (>7.63 cm)	36.0	--	31	
Duff, needles	--	15 to 20	--	
Duff, total	39.6	--	71	
Duff, lower	--	49 to 59	--	

[1] Dashes indicate no data were given.

[2] To convert to tonnes per hectare, multiply tons per acre by 2.24.

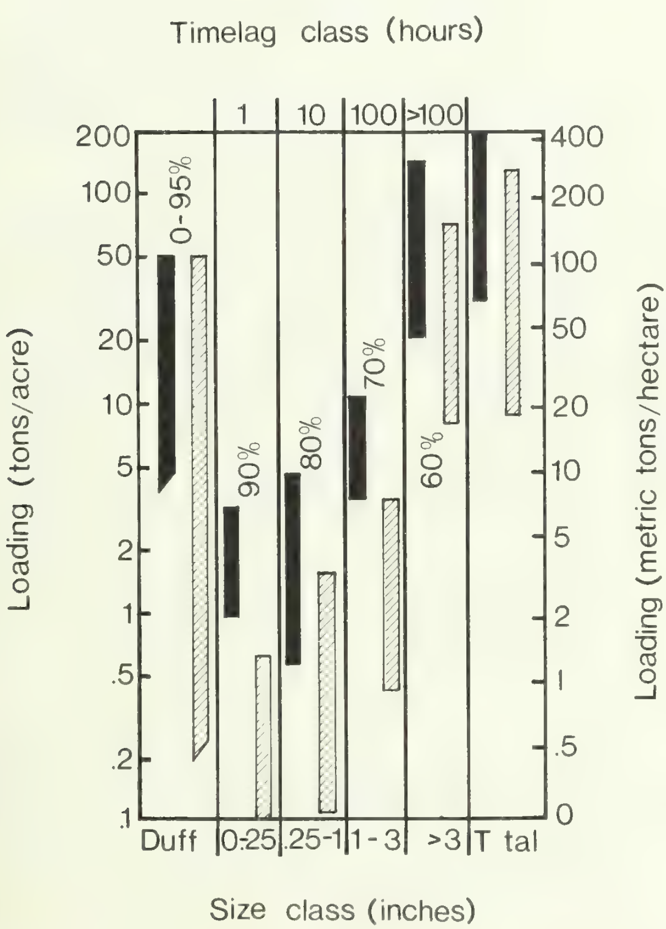

Figure 9.--Amount and consumption of various residue components before and after broadcast slash burning, as condensed from Bevins (1976) and Beaufait et al. (1975). Solid bars indicate fuel loading before burning; cross-hatched bars, after burning (figure from Martin 1977). Length of bars indicates the range of loading levels. The percent figures indicate a rough average of the amount of each size class of fuel consumed by the documented burns.

the average is about 80 percent (Beaufait et al. 1975, Bevins 1976). Generally, 60 percent or less of the larger fuels are consumed, but the percentage may vary widely. The amount of duff consumed is strongly related to the moisture content of the lower duff; consumption can vary from 0 to 95 percent. When prescribing a slash burn, the land manager will need relatively dry foliage and other fine fuels to carry the fire and generate large amounts of heat to disperse the smoke upward. It is possible to obtain the heat needed and yet leave substantial amounts of large fuels and duff for seedling shade, soil protection, and wildlife.

Prescribed burning under stands will also consume differing amounts of the fuel present. Unfortunately, we have limited data on fuel consumption by prescribed burning in this region. Burning in two diverse fuel types indicates about 70 percent of the duff (L, F, and H) layers was consumed (table 1).

NUTRIENTS AND SOIL

Nutrients vital to plants are contained in the fuels a fire consumes. The nutrients are released by the fire; their fate depends on the fire, vegetation, weather, and soil characteristics.

Most of the nutrients remain at the site after the fire (Grier 1972). Rains leach the nutrients into the soil where they may be held by cation exchange, soil micro-organisms, or plant roots. Some, however, may be leached through the subsurface water system and lost in runoff. We can expect more subsurface nutrient loss when more fuel is consumed and when soil organisms and plant roots are killed. Heavy precipitation may carry away nutrients by surface or subsurface flow.

Fire is often an important agent in recycling nutrients bound in living and dead plant materials; it improves growth potential for surviving or new vegetation. Without fire, the nutrients may remain bound for long periods and be inaccessible for growth of other plants. The released nutrients in light fires are almost all held at the site by plant roots, micro-organisms, and the soil.

Nitrogen is affected differently than other nutrients by burning. Two studies indicate 60 to 80 percent of the nitrogen contained in the fuels consumed is lost in the smoke from the fire (DeBell and Ralston 1970, Wallace 1976). Generally, this is a small part of the total nitrogen capital of the site. Even though the total nitrogen capital is reduced, available nitrogen is increased (Lewis 1974). Furthermore, nitrogen fixation may be enhanced by an increase in soil surface temperature and pH, both favoring nitrogen-fixing bacteria (Ahlgren and Ahlgren 1960, Martin et al. 1969, Bollen 1974). Fire may also stimulate nitrogen-fixing plants such as ceanothus or legumes.

Soil heating and direct damage to soil structure or biology will occur only under heavy fuel loadings, such as logs or stumps, or when burning consumes much of the duff.

The long burnout time for large fuels is the cause of soil heating. Generally, such fuels are well dispersed, so damage to the soil is not a problem. Large windrows or slash piles may temporarily sterilize areas of soil which could reduce forage or timber production.

Fire may also cause soil to become water repellent. Generally, this effect occurs after very intense, devastating fires and is probably due to condensation of certain nonwettable organic compounds in upper layers of the soil. Water-repellent soil is common in intense chaparral fires in the Southwest (Debano and Krammes 1966, DeBano 1969, DeBano et al. 1970), and some occurs after slash burning. The condition almost disappears in 5 years (DeByle 1973). Little or none should occur after light underburning or range burning. Light burning in chaparral may increase infiltration (Burgy and Scott 1952, Scott 1956, Scott and Burgy 1956).

PLANTS

The effect of fire on plants not only controls the vegetation itself but also affects animals, soil, and water. The resistance of plants to fire varies greatly between species and within species, depending on size, condition, and season of burning. Some species of plants which are individually very susceptible to fire benefit from fire because of their ability to sprout or regenerate following fire. A summary of the effects of fire on some plants is presented in table 2.

Of trees of the inland Northwest, probably ponderosa pine is most resistant to fire throughout its life. Even some seedlings 1 or 2 feet (0.3 to 0.6 m) high survive light fires, although most are killed. As ponderosa pine progresses to the mature stage, its resistance increases greatly. Thick twigs and buds are important in the tree's resistance to crown kill by fire, and the thick bark of older trees protects the main stem.

Next in fire resistance would be western larch because of the thick bark on older trees, the ability to refoliate after crown scorching, and the protected follicles. Small larch do not have the resistance of young ponderosa pine to fire.

Large Douglas-fir are quite resistant to moderate surface fires because of thick bark at the base. The crown is very sensitive to scorching, and the fine twigs and buds are readily killed by excessive heat.

Lodgepole pine is much less resistant to fire than are ponderosa pine, western larch, and Douglas-fir. But the species often does well after fire because of its ability to restock an area from seed. Although much of the lodgepole pine in this region does not have the serotinous cone habit, its reliable seed crops help compensate for the lack of seed storage.

Hemlock, true firs, and spruce succumb to fire much more readily than the other tree species do. Generally, fire reduces their numbers in an area.

The above ground portions of most perennial grasses, shrubs, and short tree species are generally killed by fire. The ability of these plants to maintain themselves in a fire regime is dependent on their sprouting and special seed characteristics. The number of these plants is so extensive that a discussion of most will not be attempted here. A great deal more information is needed on the relationship of grasses, shrubs, and herbs to fire.

Notable among species which do well in a fire regime are snowbrush ceanothus and redstem ceanothus (*C. sanguineus* Pursh.). They sprout readily following top-kill, and the seeds can be dormant for many years until activated by fire. Green rabbitbrush sprouts more frequently than does gray rabbitbrush after fire, as do bitter cherry and native perennial bunchgrasses. Bitterbrush will sprout if the burning conditions are not too severe, but the greenleaf manzanita in this area does not seem to sprout after most fires. Sagebrush is readily killed by fire.

Plant responses also vary by season and by level of physiological activity at the time of the fire. Dormant tissue will generally withstand a longer exposure to high temperature than will active tissue. Most studies have shown needles and seedling stems will withstand 120°F (49°C) for almost an hour but will succumb to temperatures of 140°F (60°C) in about 1 minute (Lorenz 1939, Nelson 1952, Silen 1963). Dormant seeds have withstood 185°F (85°C) for over 10 minutes and 167°F (75°C) for 50 minutes (Martin et al. 1969).

Growing tissue not only is more susceptible to high temperatures but is often more exposed. For instance, the dormant bud of ponderosa pine is protected by both its outer layers and old needles, but the growing shoot loses both protective mechanisms.

Trees injured by fire in the spring and summer may be subjected to insect attack before they have time to recover. On the other hand, trees injured in the autumn or

Table 2--Summary of the effects of fire on some plant species

Species	General response to fire	Comments
Trees:		
Ponderosa pine (*Pinus ponderosa* Laws.)	Probably most resistant to fire of any western tree	Often killed by crown damage from intense fires
Western larch (*Larix occidentalis* Nutt.)	Some consider it the most resistant Northwest tree; seedlings more susceptible than ponderosa pine seedlings	Able to refoliate after scorching of crown
Lodgepole pine (*Pinus contorta* Dougl.)	Killed or injured by all but light surface fires	Seeds prolifically after fire, even where not serotinous
Western white pine (*Pinus monticola* Dougl.)	Killed or injured by all but light fires	Species generally reduced by fire
Sugar pine (*Pinus lambertiana* Dougl.)	Old trees resistant to fire	Young trees susceptible to fire
True firs (*Abies* spp. Mill.)	Killed or injured by all but light fires	Species generally reduced by fire
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)	Old trees fairly resistant to fire	Young trees susceptible to fire through scorching of crown or girdling of tree; fire can be used to control species
Engelmann spruce (*Picea engelmannii* Parry)	Susceptible to all but light fires	Fire can be used in controlling species
Incense-cedar (*Libocedrus decurrens* Torr.)	Old trees resistant to fire	Young trees readily killed and species controlled by fire
Western juniper (*Juniperus occidentalis* Hook.)	Old trees somewhat resistant to all but intense fire	Fire can be used to control increase in juniper
Quaking aspen (*Populus tremuloides* Michx.)	Top readily killed by all but light surface fire	The species root-suckers profusely after fire
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)	Old trees somewhat resistant to fire where extensive root damage not caused by complete duff consumption	Species generally reduced by fire
Shrubs:		
Big sagebrush (*Artemisia tridentata* Nutt.)	Readily killed by fire; does not sprout	Fire useful in controlling species
Gray rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Brit.)	Top killed by fire; sprouting depends on burning conditions	Fire will control species; burn must be moderately hot
Green rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.)	Top killed by fire; sprouts more readily than gray rabbitbrush	Need more data on sprouting after fire
Horsebrush (*Tetradymia canescens* DC.)	Top killed by fire; some sprouting after fire	Need more data on sprouting
Bitter cherry (*Prunus emarginata* (Dougl.))	Top readily killed by fire	Sprouts readily even after intense fires
Bitterbrush (*Purshia tridentata* (Pursh.) DC.)	Top readily killed by fire	Up to 30-percent sprouting in cool moist soil after spring burning; may seed in a few years after fire
Greenleaf manzanita (*Arctostaphyllos patula* Greene)	Top readily killed by fire; does not sprout in this area	Dormancy of seeds in duff and soil broken by fire
Snowbrush ceanothus (*Ceanothus velutinus* (Dougl. ex Hook.))	Top readily killed by fire; sprouts readily	Dormancy of seeds broken by fire; repeated burns under timber may reduce ceanothus
Curlleaf mountainmahogany (*Cercocarpus ledifolius* Nutt.)	Top killed by fire; very little sprouting	Species easily controlled by fire, but often requires very dry, windy conditions to burn
Grasses:		
Bluebunch wheatgrass (*Agropyron spicatum* (Pursh.) Scribn. and Smith)	Resistant to fire, generally rejuvenated	Burning shortly after rain will reduce crown damage
Idaho fescue (*Festuca idahoensis* Elmer)	Resistant to fire	Burning shortly after rain will reduce crown damage; may recover more slowly than bluebunch wheatgrass
Bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) J. G. Sm.)	Resistant to fire	Species generally increases after fire
Cheatgrass (*Bromus tectorum* L.)	Response to fire depends on season	Fire immediately after cheatgrass cures will reduce numbers

winter will have a greater time to recover before insect activity begins.

Killing of foliage and aboveground portions by burning early in the active growing season should have a greater effect on reducing sprouting vigor. At this time, food reserves of the plant are generally low because they are used to initiate that year's growth and are not yet replaced by photosynthesis. How significant this would be in controlling shrub competition in this region is not known.

WATER

Fire may have deleterious effects on water by increasing its turbidity, changing its chemical content, and influencing flood and low water levels. Much of the data on the adverse effects of burning on water quality came from wildfires or large prescribed slash fires conducted before foresters became concerned about water quality (Tiedemann and Klock 1976, Rothacher and Lopushinsky 1974, Helvey et al. 1976).

Prescribed burning can be conducted in such a way that even small watercourses adjacent to the burn need not be modified severely. Smaller areas can be burned under moderate conditions and buffer strips left near streams to reduce negative effects. In some shrub-to-grass conversions in southwestern range burned by prescribed fire, turbidity of water was actually reduced (Ingebo and Hibbert 1974). Fire planning should involve watershed experts whenever water quality is a concern.

ATMOSPHERE

Smoke from prescribed burning is probably the greatest single factor causing public conern, and public concern in Oregon and Washington is as great as anywhere else in the Nation. The amount of smoke emitted and its dispersal are affected by how and when we burn. A slow-burning backfire spreading into the wind will emit less smoke per pound of fuel consumed than will a fast-spreading head fire (table 3).

Table 3--*Summary of best data on emissions from head fires and backfires*[1/]

Emission	Emissions from		Problems caused by emission
	Backfire	Head fire	
	Pounds per ton of fuel consumed[2/]		
Carbon dioxide (CO_2)	2,000-4,000	2,000-4,000	No major problem
Water (H_2O)	1,000-2,000	1,000-2,000	Visibility problems
Particulates	3-50	50-200	Visibility and possibly health problems
Carbon monoxide (CO)	20	150	Health problems, but only immediately adjacent to fire
Hydrocarbons (HC)	10	40	Photochemical problems
Nitrogen oxides (NO_x)	2	6	Photochemical and ozone problems
Sulfur oxides (SO_x)	0	0	

1/ High-intensity head fires emit more particulates, carbon monoxide, and hydrocarbons than backfires do; but the emissions may also be dispersed higher in the atmosphere (data from P. W. Ryan, Southern Forest Fire Laboratory, Macon, Georgia, and modified somewhat by Martin 1977).

2/ For kilograms per metric ton of fuels consumed, divide figure in table by 2.

Smoke from intense fires may disperse upward in the atmosphere, whereas smoke from low intensity fires will drift along the ground. When fire is prescribed, atmospheric stability and wind direction are important for avoiding excessive problems in smoke sensitive areas.

The major atmospheric problem caused by forest and range burning is reduction in visibility. Condensed vapor and particulates combine to form visible, generally white smoke which may obscure scenery and reduce visibility. If smoke reduces visibility on highways, dangerous traffic situations can be created.

Health problems can be caused by emissions of particulates, carbon monoxide, hydrocarbons, and nitrogen oxides. Since the amounts of these emissions that are tolerable vary with different situations, burning should be regulated as much as possible to "avoid overloading natural clearance mechanisms--both pulmonary and environmental" as suggested in the "Southern Forestry Smoke Management Guidebook" (Southern Forest Fire Laboratory 1977). The guidebook also has detailed procedures for calculating smoke impact; although these relate to situations in the South, the procedures may be helpful in the Northwest.

Carbon monoxide levels drop rapidly to nearly normal levels just outside the fire area. It is a matter of concern only for persons working close to the fire.

Over 25 hydrocarbons have been detected in slash fire smoke, and more will undoubtedly be detected by research now being conducted. The health implications of these have not been evaluated.

Nitrogen and sulfur oxides are present in minute or undetectable amounts. Temperatures of open fires are generally not hot enough to form the nitrogen oxides, and the amounts created are much less than would occur from normal biological activities. The low sulfur content of forest fuels probably accounts for sulfur not being detected in smoke.

Planning the Prescribed Burn

Planning a prescribed burn involves considerably more than just writing a burning plan, which should be considered the last step in the planning process. Most prescribed burns are part of a prescribed burning program. The burning program is part of the overall land management planning of the organization (Martin 1978).

The overall land management planning for a given large area of land is derived from the basic philosophy of management in a business organization or in the founding legislation of a government agency. From this, the management objectives for individual pieces of land having certain characteristics are developed. To achieve the objectives, the manager must consider the tools available (mechanical, manual, chemical, biological, fire) to see which might effectively and economically help obtain the objectives. Two or more types of tools together or at separate times might be used to meet the objectives. Having chosen the tool, the manager will decide on specific objectives of a treatment and on the conditions or prescription needed to accomplish it. If the treatment cannot be accomplished within constraints, the manager must reconsider which tools to use or even which objectives must be forgone for that piece of land. Finally, after treatment, the manager must evaluate

the effects of the treatment to improve future treatments or even to decide whether or not the land management objectives can be met.

Careful preparation for a prescribed burning operation should include:

1. Reconnaissance of the area, including inspection and classification of the plant community.
2. Determination of specific objectives and how these objectives fit into management goals for the land unit as a whole.
3. Analysis of budgeting, costs, manpower, equipment, and other logistical needs that must be considered in planning and accomplishing the burn.
4. Thorough review of the planned burning and discussion with other disciplines to identify potential current and future influences and impacts of the burn on all resources.
5. Scheduling of time required to accomplish planned burning for the optimum time of the year, including coordination needed with other units, agencies, etc.
6. Determination of specific prescription elements (fuel, weather, and ignition) needed to accomplish objectives.
7. Preparation of a written plan that provides a place for summary documentation of all the factors.

COORDINATION BETWEEN RESOURCES

Currently, fire is usually prescribed on east-side forests to reduce fire hazards, particularly as a method of fuel treatment on timber sale areas. This, however, does not mean that the fire manager can operate independently in planning and conducting burns. The planned prescribed burn, for whatever purpose, requires involvement of the entire management group. The burn may affect or benefit silviculture, esthetics, range, wildlife, or soil and water quality. Effects may be short term or long range, depending on method of burning, timing, season of application, prescription parameters, and many other factors. A thorough analysis must be made so that the best possible results can be obtained for all resources concerned.

Sometimes compromises and trade-offs are necessary to reach burn objectives. The dominating principle is the overall goal of land management for the unit concerned. Proper conclusions can be reached only after a thorough analysis by all principals who have a stake in the results.

Plant community analysis.--The impact of both conflagrations and low-intensity underburning on forest vegetation and soil is very evident on east-side National Forests. Hall (1976), in a comprehensive ecological evaluation of the Blue Mountains of eastern Oregon and southeastern Washington, determined that fire directly influences tree dominance and development of ground vegetation and of soil.

It is important that the land manager make a comprehensive analysis of the plant community on which prescribed burning is to be applied. This provides documentation of preburn vegetative conditons and provides a means to evaluate whether silviculture, soil, range, wildlife, fire, and other objectives are being met through fire applications.

In Region 6, area guides describe the naturally occurring plant communities within the Region (Hall 1973, Volland 1976). Each guide provides a dichotomous vegetation site key to assist field personnel in onsite identification of the plant communities; productivity data and management considerations are summarized in appendix tables.

Each site for which a prescribed burn is planned should be inspected and its vegetation described and documented; ecoclass type with accompanying descriptive data should be recorded. The description of the vegetation should be attached to and filed with each burning plan.

Environmental analysis report (EAR).--The use of fire as a forest and range management tool can affect nearly every aspect of the ecosystem--soil, air, wildlife, trees, and all other plant life. The fire manager must analyze any planned use of prescribed fire in relation to the ecosystem within and adjacent to the unit of planning.

A written environmental analysis report may be necessary for a prescribed burn, depending on the scope of effect on resources, other land uses, or the environment. The EAR might be for the major land management project (i.e., timber sale, timber stand improvement, etc.), of which prescribed burning is only a part. This report may be simple and brief if only minor impacts will occur over a small acreage; or it may be very detailed if major impacts on biotic and abiotic relationships and/or significant social and economic factors are expected. The interrelationship between these factors and the effects of the proposed project on each factor singly and together must be considered.

Forest Service Manual 8410[4/] describes the responsibilities and details for preparation of an EAR within the Forest Service. The following outline is used. Other agencies have their own formats, but the same subjects are covered. All analyses use a multidiscipline approach.

A. Summary sheet.
B. Approval page.
C. Description.
D. Environmental impacts.
E. Favorable environmental effects.
F. Adverse environmental effects that cannot be avoided.
G. Alternatives to the proposed action.
H. Relationship between short-term uses of the environment and long-term productivity.

DETERMINING BURN OBJECTIVES

The term "prescribed burning" indicates that certain variables of weather, fuel, vegetation, and management objectives will be used to set limits on how, when, and under what conditions burning will be done. The key to successful prescribed burning lies in clearly defined objectives, carefully prepared plans to meet these objectives, and proper application of fire. Objectives should not be weakly or loosely stated but should imply how the success of the burn will be measured.

Some examples of poorly stated burn objectives are:

1. To see what fire will do in a mixed conifer stand. (It just might go over the hill.)

2. To try fire as a tool in managing timber stands.

3. To reduce fuel loading.

Better statements of objectives are:

1. To reduce 1- and 10-hour timelag[5/] (TL) fuels 90 percent and 100-hour TL and larger fuels 50-60 percent.

[4/] U.S. Department of Agriculture, Forest Service. 1977. Forest Service Manual, Title 8400 - Environmental statement process, Chapter 8410 - Environmental analysis and report, sections 8410.2 to 8413, Amend. 4.

[5/] The interval in which a fuel particle loses about 63 percent of the moisture it can potentially lose under a particular set of environmental conditions.

2. To reduce 1- and 10-hour TL fuels to 3 tons per acre (7 metric tons per hectare) or less.
3. To make 90 percent of the stand area accessible to cattle and big game.
4. To kill 90 percent or more of junipers less than 10 feet (3 meters) tall and to kill 40-50 percent of all larger junipers.

In these last examples, the objectives indicate what will be measured and the levels to which the prescribed burn will probably effect a change. The manager should not, however, forget that one prescribed burn can often accomplish several objectives.

In developing a plan and objectives for a burn, the manager should remember that the burn may be only one in a comprehensive prescribed burning program with repeated burns on the same area and on adjacent areas. All the burns should fit the management goals or objectives.

DEVELOPING BURNING PRESCRIPTIONS

Burning prescriptions should meet the specific objectives on a definite piece of land. We give here some levels of prescription variables that have been successful, as well as a prescription that might be developed to meet objectives on a given piece of land where certain vegetation and fuel conditions exist.

Variables that can be used in developing prescriptions include fire, fuels, vegetation, soil, weather, time, National Fire-Danger Rating System (Deeming et al. 1978) variables, and firing technique.

Fire

The fire and its effects are the final integrators of all the prescription variables.

Flame length.--The slant length of flames is probably the most used fire variable, especially under tree canopies. Together with wind and temperature, flame length has a strong influence on scorch height. Flame length and scorch height can be estimated using Albini's (1976) publication.

Flame height.--The vertical distance from bottom to top of flames can be used but is not as helpful as flame length.

Fuels

Moisture content (MC) *by size class.*--Determines how each size class of fuel burns and how fast it will burn. Moisture content of fine fuels can be estimated from the National Fire-Danger Rating System (NFDRS) tables of Deeming et al. (1978), and MC of larger fuels measured. Low MC in fine fuels may be wanted to carry fire, but high MC in large fuels to reduce heat output.

Distribution.--Crushing or other pretreatment of fuels may be necessary to modify burning.

Duff moisture content.--Strongly influences how much of the duff will burn and the decision to expose or protect mineral soil; MC of lower duff is important in leaving a protective layer.

Vegetation

Condition.--The state of vegetation, whether active or dormant, can modify effects of fire on it; may need to use desiccant or defoliator before burning.

Moisture level.--Especially that of foliage may make a difference in whether or not it is consumed; this in turn modifies the fire characteristics.

Soil

Moisture content.--Especially important in sprouting of some plants and potential soil modification.

Weather

Relative humidity.--Strongly influences fine fuel MC and thus determines how a fire will burn, if at all; one of the most used prescription variables; also influences spotting potential.

Temperature.--Influences how fast fuels will dry and also their final MC; influences effect of fire on plants and soils.

Wind.--Very important in how fire behaves; influences scorch height; a much used variable.

Precipitation.--Especially important in affecting MC of fuels, plants, and soil; a good general index of when to get ready to burn.

Time

Season.--Very important as it relates strongly to plant conditions, sprouting, seed sources, and potential insect attack.

Diurnal.--Daily changes in temperature, humidity, and wind can help achieve prescription condition.

National Fire-Danger Rating System

The 1978 system (Deeming et al. 1978) should be more useful than older systems; may use fuel MC, temperature, wind, etc., as well as burning index, energy release component, ignition component, and spread component.

Firing Technique

Used to modify fire under any given conditions; important in allowing wide variation in other variables, yet meeting objectives.

Selecting the Variables

Whatever the prescription variables, *the final integrating factors are the fire and its effects.* If the fire is not accomplishing the objective, the manager should modify the burning procedure accordingly. Burning crews must know what kind of fire is wanted so they can report differences and adjust their lighting procedures. If adjusting the procedure does not meet the prescription, then the burning should be postponed until the objectives can be met.

With any prescribed burn, there will usually be both ideal and satisfactory levels of meeting objectives. As an example, if red thinning slash is being burned under a stand 60 feet (18 m) tall, an ideal plan would remove almost all the 1- and 10-hour TL fuel classes and 40 to 60 percent of the larger classes. If, however, it has recently rained and a hot, dry summer is almost here, it is more desirable to reduce the fines as much as possible to keep from carrying red slash through the summer, even though reduction of the larger fuels will be minimal.

Use of only one or two prescription parameters by themselves may not give a sensitive enough prescrption to meet the manager's objectives. As an example, in prescribing a burn under ponderosa pine, the manager should not say simply that the prescripton for a fall burn will be for a given temperature, wind, and relative humidity. Most likely, the manager will also want to prescribe 1 or more inches of rain in September within a week before the burn, this would insure some wetting of larger fuels, increased moisture in soil and duff, and less flammable foliage.

As a prescribed burning program is developed, prescriptions can often be broadened and simplified. A major reason for this is that the fuel loadings under a stand of trees would have been reduced and made more uniform by the second or third time the area is burned. Often the broadening will be toward the more severe fire weather conditions--lower humidities and fuel moistures, higher temperatures and winds. A second reason prescriptions may be broadened is the more sensitive application of fire by the burning crews as they develop skills in prescribed burning.

Before we discuss prescriptions for various situations, there are some general points to consider.

1. In burning under tree canopies, wind is desirable unless the crowns are so high and the flames so low that there is no problem with scorching the crowns. The wind not only increases the distance the heat must travel to the crown but also increases the smoke's mixing with cooler air, both of which reduce temperatures in the crowns.
2. Certain prescription parameters may override others. For instance, flame lengths may override fuel moisture and humidities, as the flames are the final factor in the outcome of the treatment.
3. Any prescriptions used must be adjusted to the site conditions in the burn area. The prescriptions used in an old-growth stand probably would not serve well in a small pole stand. The prescription for burning in pure pine surface litter will not work where heavy needle drape occurs in shrubs.
4. When one or more prescription parameters are adjusted toward a more severe fire condition, there should usually be an adjustment of others toward a less severe condition. Generally, all the parameters should not be in the most severe or least severe conditions.
5. Where conditions vary within the burn area, the prescription should be adjusted. Burning in stages to remove fuel concentrations or needle drape under very moderate conditions and later burning the rest of the stand may be suitable.
6. Prescription levels as summarized in table 4 are only guides to developing prescriptions.

Several sources for help in developing prescriptions are Albini (1976)--estimating scorch heights, flame lengths, rate of spread, and energy release; Brown (1974)--measuring down and dead woody fuels; Brown et al. (1977)--estimating how much slash will be produced; and Deeming et al. (1978)--following weather variables and predicting fire behavior (dummy stations should be established at burn site).

FIRING TECHNIQUES

Firing a prescribed burn unit may be accomplished in various ways, depending on intensity of fire needed to meet objectives.

Based on fire behavior and spread, a prescribed burn moves either in the same direction as the wind (head fire), in the opposite direction (backfire), or at a right angle to the wind (flank fire). Other variations that may be considered are spot fires, center fires, or ring fires.

Vegetation	Miles per hour	Kilometers per hour	Relative humidity	content of fine dead fuels	Temperature	Season	Precipitation	Fireline	Firing pattern	Comment
			- - - Percent	- - -						
Sagebrush, rabbitbrush, horsebrush, bunchgrasses, cheatgrass:										
Much dead, woody fuel	7-12; gusts to 15	11-19; gusts to 24	20-25	5-15	50^{o}-90^{o}F (10^{o}-32^{o}C)	Spring, early summer, fall	One or more days after significant rain if it is a fall burn	Burn out to at least 200 ft (60 meters) on downwind side; need less burnout for grass	Strip head fire, head fire, ring, or center fire	Rest land from grazing in summer before burning to increase fuel continuity for better spread
Little dead, woody fuel	7-12; gusts to 15	11-19; gusts to 24	15-25	5-12	50^{o}-90^{o}F (10^{o}-32^{o}C)	Spring, early summer, fall	One or more days after significant rain if it is a fall burn	Burn out to at least 200 ft (60 meters) on downwind side; need less burnout for grass	Strip head fire, head fire, ring, or center fire	Rest land from grazing in summer before burning to increase fuel continuity for better spread
Cheatgrass	3-12; gusts to 15	5-19; gusts to 24	20-30	8-13; duff should also be dry	50^{o}-80^{o}F (10^{o}-26^{o}C)	Early summer	Sufficient time for duff to dry	Burn out to 50 ft (15 meters) on downwind side	Strip head fire, head fire, ring, or center fire	Burn in early summer as soon as cheatgrass is cured to reduce cheatgrass density and seed load
Bitterbrush, mountainmahogany:										
Much dead, woody fuel	1-7; little gusting	2-11	25-35	6-12	60^{o}-90^{o}F (16^{o}-32^{o}C)	Spring, early summer, fall	No data	Burn out to 50 to 200 ft (15 to 60 meters) on downwind side; then proceed slowly, depending on wind and fuel moisture	Backfire, strip head fire, ring or center fire	Burning when soil is in cool, moist condition in spring or early summer may result in up to 25-percent sprouting of bitterbrush
Little dead, woody fuel	5-10; gusts to 12	8-16; gusts to 19	20-25	5-10	60^{o}-90^{o}F (16^{o}-32^{o}C)	Spring, early summer, fall	No data	Burn out to 50 to 200 ft (15 to 60 meters) on downwind side; then proceed slowly, depending on wind and fuel moisture	Strip head fire, ring, or center fire	Burning when soil is in cool, moist condition in spring or early summer may result in up to 25-percent sprouting of bitterbrush
Ponderosa pine, with understory of fir, cedar, bitterbrush, mountainmahogany, ceanothus, manzanita:										
Much dead, woody fuel and needle drape	3-7 in stand	5-11 in stand	30-85	8-12	20^{o}-80^{o} (-7^{o}-26^{o}C)	Spring, early summer, fall, or winter; avoid midsummer	One or more days after significant fall rain	Slowly widen lines with backfires and strip head fires	Backfire, strip head fire, flank fire; may want to burn in stages	Winter burning when ground is frozen may result in excessive needle desiccation and stand reddening but little permanent damage to stand
Little dead, woody fuel and needle drape	1-10 in stand	2-16 in stand	20-50	5-12	20^{o}-80^{o}F (-7^{o}-26^{o}C)	Anytime, once stand is in condition	No data	No data	Once stand is in condition can also use head fire	Burning heavy needle drape, particularly in bitterbrush in low crowns, can be accomplished shortly after rain with humidities to 85 percent; may need to complete burn in second stage to consume other fuels
Larch-fir (Norum 1977)	Less than 8	Less than 13	25-60	No data	50^{o}-75^{o}F (10^{o}-24^{o}C)	No data	No data	No data	Strip head fire	Once stand has been conditioned with prescribed burning, prescriptions can

Table 5 provides a quick guide to the various firing techniques used in prescribed burning. The following summary and figure 10 describe each technique in detail:

Head fire.--The head fire technique will generally produce the largest area burned per unit of time and with a minimum of ignition. The method can be used in shrub or grass areas, in clearcut areas where wide firelines have been established, and under timber stands where previous burning has reduced surface fuels to a sufficiently low level and ladder fuels are not present. It is not recommended for early stages of prescribed burning under tree canopies.

Downwind firelines should be wide enough to prevent the fire from jumping or spotting across the line. Wright (1974) recommends a 100-foot (30-m) fireline for grass fuels and a 400-foot (120-m) fireline for piled juniper and other fuels that produce embers, and relatively high wind conditions. The wide lines are constructed with plowlines on each side; the intervening distance is burned out under moderate burning conditions. Instead of plowed lines, it is possible to use wet lines, with or without retardants, where duff is not deep; and it is desirable to not leave permanent scars (Martin et al. 1977). The Bend Silviculture Laboratory has used this technique in prescribed burning research at Lava Beds National Monument. In light needle litter under timber stands, downwind firelines backfired to a width of 10 or 20 feet (3 to 6 m) would be adequate for the burning conditions normally selected. If conditions or fuels were worse than that, one should not be using head firing under those stands.

Backfire.--The backfire is the gentlest and slowest moving fire. It is lighted on the downwind side and allowed to creep upwind through the area. Internal lines may be constructed within the prescribed burn area, then backfires started at each. The slow rate of spread and considerable internal line construction generally make backfiring more expensive than other methods of burning. Once internal lines are built to a certain orientation, the burner is committed to a given wind direction with which he must burn.

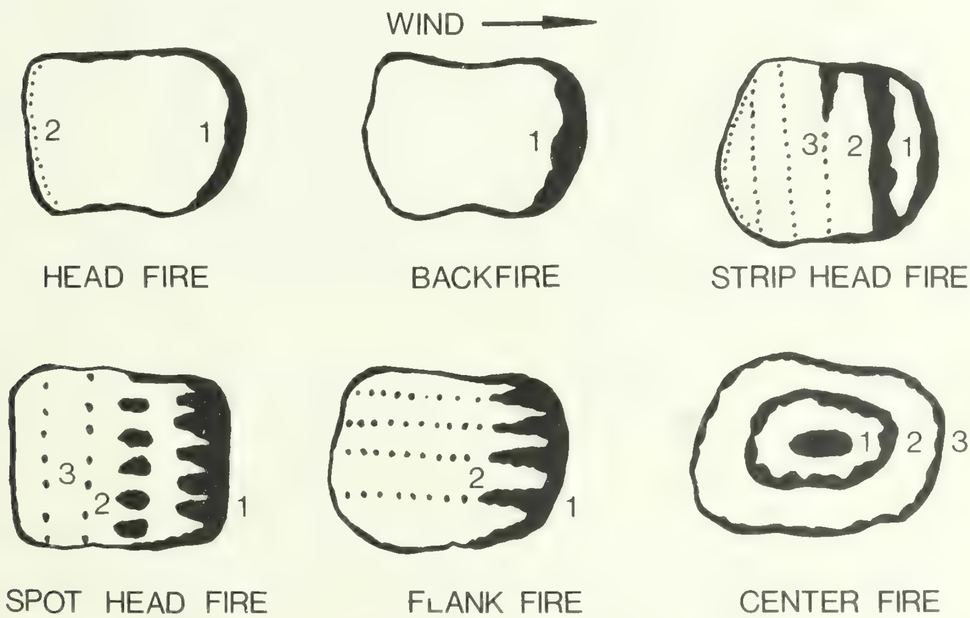

Figure 10.--Basic firing techniques used in prescribed burning. The numbers indicate the sequence of ignition.

Table 5--Firing techniques for prescribed burning [1/]

Technique	Where used	How done	Advantages	Disadvantages
Head fire	Large areas, brush fields, clearcuts, under stands with light fuels	(1) Backfire downwind line until safe line created (2) Light head fire	Rapid, inexpensive, good smoke dispersal	High intensity, high spotting potential
Backfire	Under tree canopy, in heavy fuels near firelines	(1) Backfire from downwind line; may build additional lines and backfire from each line	Slow, low intensity, low scorch, low spotting potential	Expensive, smoke stays near ground, the long time required may allow wind shift
Strip head fire	Large areas, brush fields, clearcuts, partial cuts with light slash under tree canopies	(1) Backfire from downwind line until safe line created (2) Start head fire at given distance upwind (3) Continue with successive strips of width to give desired flames	Relatively rapid, intensity adjusted by strip widths, flexible, moderate cost	Need access within area; under stands having 3 or more strips burning at one time may cause high intensity fire interaction
Spot head fire	Large areas, brush fields, clearcuts, partial cuts with light slash, under tree canopies; fixed-wing aircraft or helicopter may be used	(1) Backfire from downwind line until safe line is created (2) Start spots at given distances upwind (3) Adjust spot to give desired flames	Relatively rapid, intensity adjusted by spot spacing, can get variable effects from head and flank fires, moderate cost	Need access within area if not done aerially
Flank fire	Clearcuts, brush fields, light fuels under canopy	(1) Backfire downwind line until safe line created (2) Several burners progress into wind and adjust their speed to give desired flame	Flame size between that of backfire and head fire, moderate cost, can modify from near backfire to flank fire	Susceptible to wind veering; need good coordination among crew
Center or ring fire	Clearcuts, brush fields	(1) For center firing, center is lighted first (2) Ring is then lighted to draw to center; often done electrically or aerially	Very rapid, best smoke dispersal, very high intensity, fire drawn to center away from surrounding vegetation and fuels	May develop dangerous convection currents; may develop long distance spotting; may require large crew

[1/] Martin (1977).

Backfires generally require lower fuel moisture in fine litter fuels than do head fires or flank fires. They also require better fuel continuity for fire spread, as the short flames reach back over the burned out fuel rather than ahead into fresh fuel. The backfire may consume more fuel than a head fire does, especially if the duff contains some moisture.

When surface litter fuels are sufficient to carry a backfire and lower litter and duff layers are moist, the backfire may tend to burn deeper into these fuels than a head fire does. The head fire may rapidly skim over the surface layers, whereas the flames of the backfire radiate heat into the burned-over area, often drying them sufficiently to burn.

Slopes may be used effectively for backfiring when little or no wind is present. Often it is possible to start a fire on a ridgetop and have it back down both sides, or from a hilltop and have it back down in a circular fashion.

Strip head fire.--The strip head fire is probably the most versatile method of prescribed burning. The downwind line is backfired to provide a fireline sufficiently wide to prevent the first strip head fire from jumping it. After that, each strip head fire is lighted a distance upwind that will keep flame lengths (and fire intensity) below the maximum the burner feels are tolerable for the prescription. If conditions change or different fuel complexes are encountered, the strip width can be adjusted to give the desired fire. If, within the burn area, small areas of very heavy fuels are encountered, it may be desirable or necessary to back a fire through that area.

Strip head fires are generally of variable intensity. The lowest intensity is where the fire on the upwind side of each strip backs into the wind. It is a relatively narrow area as the head fire side spreads much more rapidly. As the head fire spreads from each strip, its intensity, flame length, and rate of spread may increase or decrease, the result depending on fuels and burning conditions. Generally, however, intensity will increase as the head fire spreads. The lighter must then adjust the strip width to hold fires within the desired intensity. The hottest portion of the burn will be where the head fire from one strip and the backfire from the previous strip meet. At this point, the two fires interact to produce the largest flames, highest intensity, and greatest vertical convection.

Strip head firelines should be kept relatively straight and normal to the wind. Deep curves in the line can cause the fire on each side to interact and produce a very intense local fire. A strong vertical convection column can then cause scorching or even torching of the tree crowns.

Another situation to avoid if vertical development of the fire is of any concern is three or more strip head fires burning at one time. The fire interaction among strips is most prevalent where fuels are heavy and flashy, winds light, and strips closely spaced. Scorching or torching of crowns can occur readily where the fires interact.

Spot head fire.--The spot head fire is similar to the strip head fire except that spot fires are started as a line of spots rather than continuous lines of fire. Each spot fire typically burns independently in an elliptical pattern of individual fires until it burns close to another spot fire, at which time interaction between the two may occur.

Spot head fires may give a great degree of variability in results as each spot will burn with varying intensity, ranging from the low-intensity backfire to intermediate-intensity flank fire to high-intensity head fire. The spot head fire is particularly appropriate when ignition can best be accomplished with a series of spot fires, such as from aircraft or other encapsulated means of ignition.

Flank fire.--The flank fire is intermediate in intensity between the head fire and backfire. As it spreads across the wind, it may develop small head fires and

backfires because of irregularities in fuel and wind. Several lighters start lines of fire as they walk simultaneously into the wind, and the fires spread out in a V behind them. Eventually the fires from each lighter merge and form a burned out area. Steepness of the V's depends on relative speed of the lighter and the flanking rate of spread of the fire. Where two adjacent fires merge, a line of higher intensity fire is produced because of fire interaction. If winds veer much, the flank fires may become a series of head fires and backfires, with varying intensity.

A type of flank fire known as the chevron burn is often used on the ends of ridges; the pattern is produced by each burner walking downhill beginning at the ridge line. Similarly, the slope of a hill could be used in place of a wind. A starburst pattern may be created if flank fires are started by lighters walking downhill from the crest of round hills, such as many of the buttes in eastern Oregon and Washington.

Center or ring fire.--This method is used to develop high intensity fires, rapid burnout, and vertically dispersed smoke. Its most common use is in slash burning, but it can be used in any situation where available fuels can produce fire intensities high enough to overcome winds and there is no concern for trees within the burn. The indraft draws fire away from surrounding fuels and tree crowns. Although the high intensity may produce more embers, these will be drawn upward with the smoke column and must travel a much greater distance before coming in contact with new fuel than they would in a fire leaning over new fuel.

Lighting begins with a center ring of fires of such a diameter that the fires will draw toward the center. As the intensity increases, the draft from outside the area will increase, so that the next ring of fire will be drawn toward the center and further increase total heat release rate and indraft. Finally, the outer perimeter of fire is lighted. On slopes or with some wind, the upslope or downwind line may have to be widened or the lighting modified so that the indraft will be sufficient at all times.

IGNITION METHODS

Once the firing techniques are decided on, the method of ignition can be chosen. The firing technique, as well as the fuel-vegetation complex and the size of the area to be burned, will put constraints on the ignition method. Common methods are given in table 6. Although many methods are available, the drip torch still appears to be the most common and most economical.[6/]

LOGISTICS

Logistics is the art of bringing together all the required resources (equipment, supplies, and manpower) at the right place and time. It is important to develop this well head in planning; especially at the start of a prescribed burning program, there may be a need to purchase new equipment or arrange some manpower exchange to supplement crews.

For the short term, arrangements must be made to have crews and equipment at given locations at given times. Both crew and equipment needs will change--in preparing the unit for burning, in conducting the burn, and in postburn mopup and treatment.

[6/] Muraro, S. J. 1975. New ignition systems. Paper presented to the West For. Fire Comm., Vancouver, B.C.

Table 6--Ignition methods for prescribed burning[1/]

Method	Where used	How used	Advantages	Disadvantages
Flamethrower	Slash or brush; broadcast or jackpot burning	Burner walks firelines or skid trails and ignites fuel combinations	Fastest hand-carried igniter; burner can reach several feet with flame to avoid walking in slash brush	Somewhat more expensive and complicated than drip torch, heavier to carry and uses more fuel than drip torch does
Drip torch Drag torch	Almost any situation	Burner walks firelines, trails or through fuels, dropping burning fuel	Simple, light, inexpensive, reliable equipment	Slower than flame thrower; burner must often move through heavy fuel
Helitorch	Clearcut slash; could be used in brush or other low vegetation	Helicopter carries large drip torch in sling; drips burning fuel	Very fast ignition; not committed to predetermined firing plan	Helicopter expensive; safety not yet determined
Electrical ignition (primacord/ jellied gasoline)	Clearcuts in west coast States; heavy slash and smoke dispersion considerations	(1) Primacord is wrapped around metal or plastic containers of jellied gasoline (2) Electrically detonated in desired pattern	Extremely rapid ignition and convective buildup; excellent for smoke dispersal	Expensive to wire; once wired must burn
Fusees	Anywhere; best used as an auxiliary to other methods when needed	Burner walks fireline or trails or through fuels; must hold flame to fuel for short period to insure ignition	Inexpensive, light; can be carried in vest or pocket to use as auxiliary method	Very slow; must pause to hold flame to fuel; expensive in labor time to start fire
6-inch igniter cord-safety fuse (DAID'S)	Large or remote areas, from aircraft; Australia, Everglades	(1) Ignited by cigarette lighter (2) Dropped from plane or helicopter to start spot fires (3) Flames 15-20 seconds after ignition	Can ignite remote areas; intermediate expense; can cover large area	Dangerous if mishandled or in crash
Potassium permanganate/ ethylene glycol capsules	Large or remote areas, from aircraft; Australia	(1) Chemicals mixed by liquid injection (2) Dropped from plane or helicopter to start spot fires (3) Ignites 30-60 seconds after mixing	Capsule and contents inexpensive; can easily cover large areas	Best only for large remote areas

[1/] Martin (1977).

THE WRITTEN BURNING PLAN

Prescribed burning requires a knowledge of fire behavior, control strategy, suppression technology, and the effect of fire on the environment. If an effective and safe prescribed burn that will meet management objectives is to be developed, a burning plan that considers all planning elements must be prepared. On extremely large or very complex burns, supplemental plans and instructions may be necessary. In most situations, however, a burning plan format similar to the example shown in figure 11 will adequately document detailed planning.

The plan should be prepared well in advance of the burning season to allow for selection of burn unit, preburn evaluation, planning strategy, interfunctional coordination, and any necessary arrangements for financing, manpower, equipment, and other needs.

Size of unit to be burned will vary, but each area for which a plan is being prepared should be fairly uniform in topography and type and amount of fuel. In an area where broad variations in these elements exist, developing an effective burning prescription is difficult, if not impossible. It is better to divide such areas into several burn units, as practical, and prepare a separate burning plan for each.

The following guidelines should be used to prepare a burning plan.

PRESCRIBED BURNING PLAN

FOREST	DISTRICT	FY-
TRI COMPARTMENT (NAME & NUMBER)	GRID NUMBER	BURN UNIT
LOCATION: T_______, R_______, S_______	GROSS AREA	NET AREA
I&E CONTACTS	APPROPRIATION(S)	
	EAR PREPARED BY	DATE

BURN AREA DESCRIPTION: DESCRIBE TREES & SHRUBS OVER 12 FEET TALL, SHRUBS & TREES UNDER 12 FEET, AND GRASSES AND FORBS.

ECOCLASS CODE(S)__________ TOPOGRAPHY__________ SLOPE__________ ASPECT__________

SOIL TYPE(S) & DESCRIPTION__________

FUELS (NATURAL &/OR ACTIVITY)

0 -¼" SIZE CLASS__________T/A SHRUBS__________T/A TOTAL__________T/A

¼"-1" SIZE CLASS__________T/A HERBACEOUS__________T/A

1"-3" SIZE CLASS__________T/A DUFF DEPTH__________IN FUEL CLASSIFICATION__________

3" + SIZE CLASS__________T/A SURFACE FUEL DEPTH__________FT NFDR FUEL MODEL__________

MANAGEMENT GOALS OF THIS BURN

OBJECTIVES OF BURN	(CHECK)	(SPECIFICS)
HAZARD REDUCTION		
SILVICULTURE		
SITE PREPARATION		
WILDLIFE HABITAT		
RANGE MANAGEMENT		
INSECT/DISEASE CONTROL		
SPECIES MANIPULATION		
OTHER		

BURNING PRESCRIPTION

SEASON__________ TEMPERATURE (RANGE) ____to____ °F WIND DIRECTION:

TIME OF DAY__________ RH (RANGE) ____to____ % PREFERRED__________

DAYS SINCE RAIN__________ WIND SPEED (RANGE) ____to____MPH ACCEPTABLE__________

FUEL MOISTURES: 1 HR TL__________%, 10 HR TL__________%, 100 HR TL__________%,

1000 HR TL__________%, DUFF__________%, SHRUB__________%, HERBACEOUS__________%

FLAME LENGTH: MAXIMUM__________, AVERAGE__________ FLAME HEIGHT__________

ALLOWABLE SCORCH HT (FT): CROWN____, BOLE____ NFDR DATA: BI____, ERC____, IC____, SC____

FIRING PATTERN__________ IGNITION METHOD__________

LOGISTICAL INFORMATION

CHAINS LINE TO CONSTRUCT: TRACTOR____ HAND____ OTHER (SPECIFY)____ TOTAL__________

CHAINS LINE TO FIRE: EXTERIOR____ INTERIOR____ TOTAL____

MANPOWER NEEDS: UNIT PREPARATION__________ BURNING__________

HOLDING__________ MOPUP__________

EQUIPMENT NEEDS: UNIT PREPARATION__________

BURNING__________

HOLDING__________

MOPUP__________

BURN SUMMARY

DATE BURNED__________ TIME OF DAY__________ DAYS SINCE RAIN____ SEAS. PRECIP TO DATE____IN.

ACTUAL WEATHER: TEMP____ RH____ WIND SPEED & DIRECTION__________ NFDR BI____

FUEL MOISTURES: 1 HR____ 10 HR____ 100 HR____ 1000 HR____ BRUSH____ HERBACEOUS____

FIRE BEHAVIOR: ROS__________CH/HR, AVERAGE FLAME LENGTH__________FT, HEIGHT__________FT

SCORCH HEIGHT: BOLE__________FT, CROWN__________FT

BURN EVALUATION (If additional space is needed, use additional sheet)__________

PLAN PREPARED BY:__________ DATE__________

PLAN REVIEWED BY:__________ DATE__________

PLAN APPROVED BY:__________ DATE__________

NOTE: ATTACH MAP OF BURN AREA

Figure 11.--Prescribed burning plan format.

Location and Unit Information

- Enter National Forest or administrative unit or code numbers.
- Enter fiscal year in which unit will be burned.
- If appropriate, enter any special descriptive codes for locating units in conjunction with an information storage and retrieval system, such as Pacific Northwest Region's Total Resource Information System.
- Enter burn unit name and/or number.
- Enter township (T), range (R), section (S).
- Enter gross area in acres. Include all acres within burn unit boundary (including "leave" islands, etc.).
- Enter net area in acres. Include only the acres that will actually be burned.
- Enter appropriation number to which burn project should be charged.
- Enter initials of person who prepared Environmental Analysis Report (EAR) and date of approval. Note: EAR may have been prepared for a timber sale in which the prescribed burning unit is located. In such a case, any burning would be considered part of the environmental analysis of the parent project.

Information and Education (I&E)

- Briefly describe public and/or in-Service I&E contacts to be made (local media, residents, landowners, recreationists, etc.).

Burn Area Description

- Describe vegetation in detail; stand examination information, if available. *Attach the form to the burning plan.*
- Identify ecoclass code (Forest Service) or other ecological designation.
- Describe topography (flat, broken, steep, etc.).
- Enter slope percent and aspect (direction slope faces).
- Identify soil type and briefly describe characteristics.
- Enter fuel tonnages and duff and litter depth from preburn fuel inventory data.
- Designate fuel type classification (i.e., HM, HH, LM, etc.)[7/]
- Designate the National Fire Danger Rating (NFDR) fuel model most appropriate for the area.

Management Goals

- Describe general management goals for this land unit and how this application of prescribed fire will help meet these goals.

Objectives of Burn

- Check one or more objectives of prescribed burn and briefly explain specifics (see "Determining Burn Objectives", page 16).

[7/] The letters refer to Forest Service Pacific Northwest Region's system of fuel hazard rating. The first letter designates the rate of spread; the second, resistance to control. Ratings are only relative: E = extreme, H = high, M = medium, L = low.

Burning Prescription

- Identify season of year and time of day when burn will be accomplished.
- Designate preferred number of days between last precipitation and planned burn date.
- Designate specific ranges of temperature, relative humidity (RH), and wind conditions that will produce the best environment to achieve objectives.
- Designate desired fuel moisture percentages by size class to achieve needed fuel consumption.
- Describe desired flame length and height in feet that will achieve necessary fuel consumption and keep scorch heights to designated levels.
- Designate optimum NFDR BI (burning index), ERC (energy release component), IC (ignition component), and SC (spread component). Refer to "The National Fire-Danger Rating System" (Deeming et al. 1978). Specify firing pattern to be used (back, strip head, flank, center, etc.) and ignition method (drip torch, aerial, remote, etc.).

Logistical Information

- Specify chains of tractor, hand, or other exterior or interior line to be constructed.
- Specify chains of exterior or interior lines to be fired.
- Identify specific manpower and equipment needs for the various phases of the burning program.

  Note: If more space is needed to describe special requirements, use additonal sheets of paper.

Burn Summary and Evaluation

- Indicate date the burn was accomplished and time of ignition. Record number of days since last actual precipitation and amount of total precipitation for season to date of burn.
- Summarize actual weather, fuel moistures, and burning index on day of burn (from observations taken *onsite* during the burn).
- Record actual observed rate of spread (ROS) of fire, and average flame lengths, flame heights, and scorch heights for boles and crowns.

A good burn evaluation will require more space than allowed for on this form. Evaluation is an extremely important part of the documentation needed for a prescribed burn project. It will provide the history and background necessary for making future prescribed burning decisions.

Evaluation should be done in two phases, short term and long term. There are some obvious effects of a burn that are evident almost immediately and should be recorded. A thorough evaluation, however, may require several trips to the site at time periods after the burn. This evaluation should include, but is not limited to, some of the following specific items:

Fuel consumption.--How much was fuel amount reduced (i.e., by size class, duff depth, etc.)?

Fuel classification.--What is the fuel hazard classification for the area?

Soil exposure.--On what percent of area has soil been exposed?

Vegetative effects.--What happened to grasses, forbs, shrubs, and trees?

Visual impacts.--What problems, if any, affect management of the visual resources of the area? What can be done to correct them?

Plan Preparation and Approval

- Record names of individuals preparing, reviewing, and approving the burning plan.
- Date each entry.

Execution of the Prescribed Burn

If a thorough planning job is done, the prescribed burn can be accomplished in an efficient and safe manner.

The burning boss should assemble and organize the crew in sufficient time to allow a thorough orientation and briefing. Firing, holding, and mopup equipment must be ordered, assembled, and checked out well ahead of scheduled burning. Communications equipment, transportation, food, and water needs must be considered and allowed for.

A brief checklist for the burning boss follows:

1. Brief crews completely on burn objectives, procedures, safety, and contingency plan if problems develop.
2. Distribute copies of burning plan, maps, photos, or other instructional material needed.
3. Have current weather forecast in hand and be prepared to receive updated weather information throughout the day. Be aware of current smoke management conditions and necessary requirements.
4. Have a belt weather kit on hand for periodic observations, or have a crewmember assigned this task. Keep yourself and crew informed.
5. Check firelines and other preparations. Reinforce or modify firelines as needed.
6. Notify local residents, media, and fire organizations of intentions to burn.
7. Post road signs and/or assign traffic controllers if smoke will reduce visibility on travel access routes.
8. Check moisture of fuel and soil.
9. Notify headquarters of ignition time.
10. Set a small test fire in unit before start of regular firing.
11. From results of test fire, *MAKE DECISION TO PROCEED OR HOLD.* Inform all parties.
12. If decision is to proceed, be alert to changing conditions--keep crewmembers advised.
13. Have sufficient personnel lined out for mopup and patrol of perimeters throughout all phases of the operation.
14. If conditions change or fire is not behaving as desired, modify ignition to get proper burning or STOP. If the decision is to stop, put out fire and proceed with mopup.
15. Do not leave burn area until you have personally completed the "BURN SUMMARY" portion of the prescribed burning plan.

Other Prescribed Burning Guidelines

In preparing this guideline, we have drawn from Allen et al. (1968), USDA Forest Service (n.d., a and b) Beaufait (1966), Mobley et al. (1977), Wright (1974), and U.S. Department of the Interior, Bureau of Land Management.[8] We have tried to modify the best parts of each to fit eastern Oregon and Washington.

Sample Burning Situation

Your district has a variety of vegetation habitat types, from sagebrush-bunchgrass to mixed conifer-ceanothus. In one area, the transition from open range to the upper-slope mixed conifers occurs within a few miles (fig. 12); we will talk about burning in this area. A major highway travels from northwest to southeast, and most of the sagebrush types lie to the west of it. Elevation increases to the northeast; vegetation gradually changes to types requiring cooler, moister sites. The area has many small vehicle trails and one road used extensively by recreationists to get to Blue Lake, nestled among mixed conifers. Facilities at the lake include a guard station, lodge, cabins, and an improved campground.

The climate in the area is typical of what might be expected in eastern Oregon and Washington. Precipitation comes mostly between September and May. June, July, and August are generally quite low in precipitation; humidity is low during the warm, clear summer days. Dry lightning storms are common during the summer months. Your analysis of fire causes shows that two-thirds of the wildfires are caused by lightning. In an area around Blue Lake, risk from man-caused fires is high--specific causes vary but generally reflect the high recreation pressures in the area.

Your brief analysis of fire scars conducted for fire history information shows that fires have been frequent in the area--the average period between fires ranges from 5 to 10 years in the lower elevations and 35 to 40 years in the higher elevations. The acreage burned has decreased greatly in the past 60 years as fire control has improved. Fire control has made it possible for you to practice forest management, but some problems are now evolving. There are some biological problems pointed out by the resource staff, such as increases in insect susceptibility and mistletoe infestation and reduction in tree and forage growth; and the fuels assistant has indicated that fuel accumulation could lead to catastrophic fires.

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[8] U.S. Department of the Interior, Bureau of Land Management. 1976. Prescribed fire handbook. Missoula, Mont.

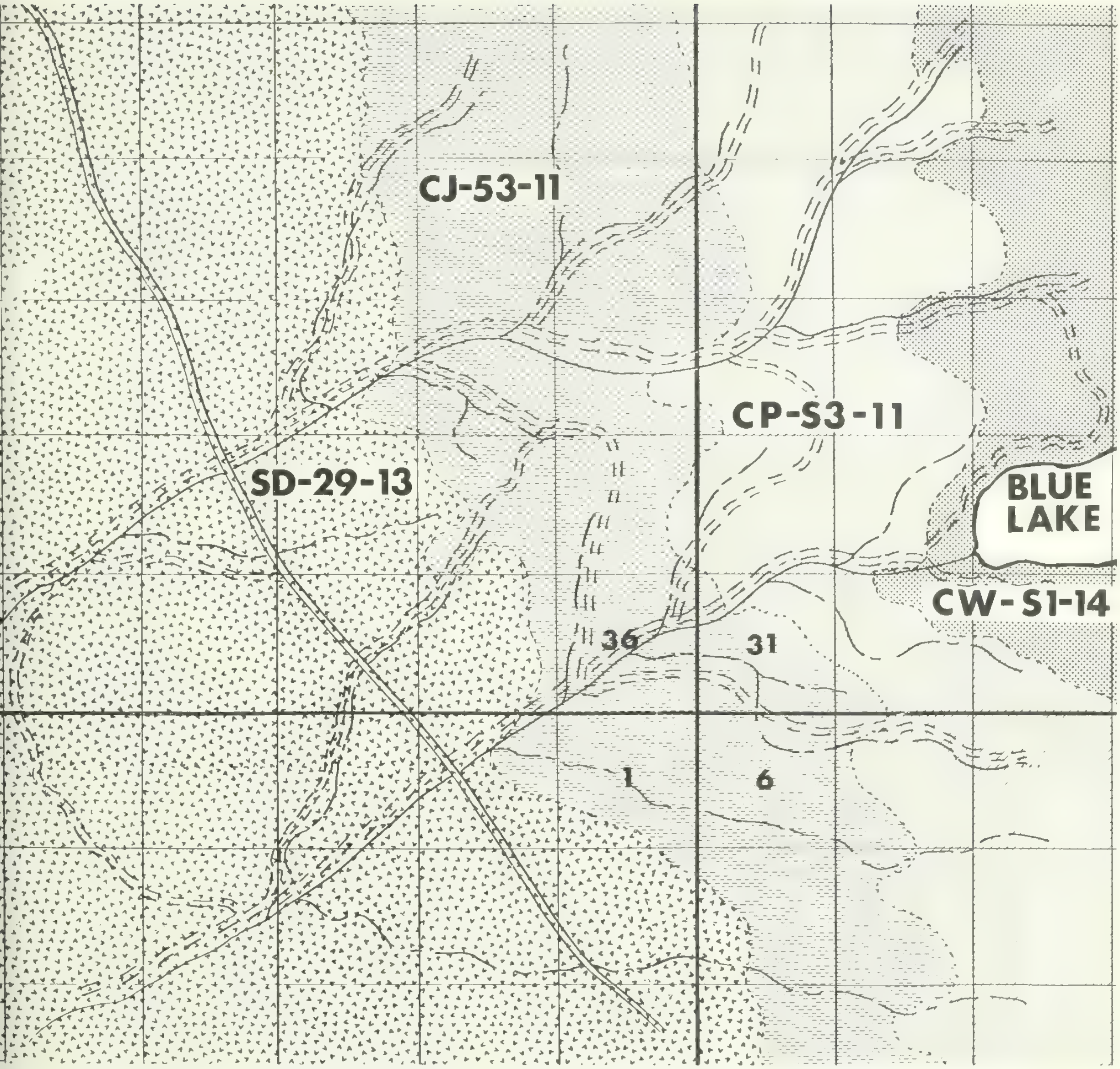

Figure 12.--The area in which you are considering use of prescribed fire. Vegetation varies from sage-grass (SD-29-13) in the warmest, driest area, through juniper-bitterbrush-bunchgrass (CJ-53-11) and ponderosa pine--bitterbrush-snowbrush (CP-S3-11) to mixed conifer-snowbrush (CW-S1-14) on the highest, coolest, wettest areas.

A quick look at the area suggests the first consideration for modifying fire potential should be done to protect the high values at risk around Blue Lake. Records indicate most of the wildfires have moved from the southwest, west, or northwest (fig. 13). You develop a plan calling for a fuel break system that would help protect the Blue Lake environs from wildfires on the north, west, and south.

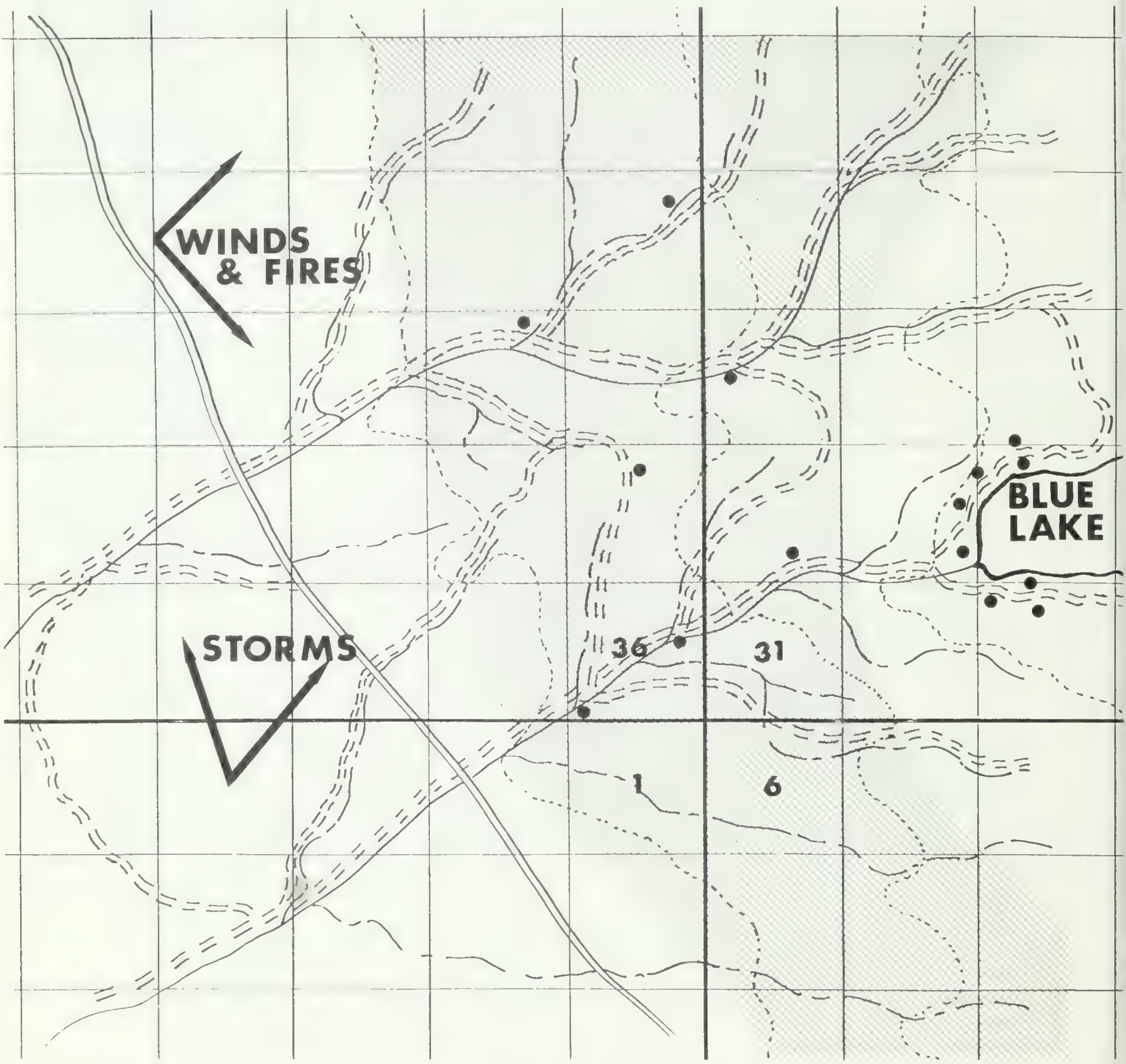

Figure 13.--The fire situation in Blue Lake area. Most wildfires have moved from the southwest to northwest quadrant. Man-caused fires (dots) have been centered around Blue Lake, and lightning-caused fires have been started in a broad belt west of the lake (cross-hatched area).

(The fuel break would also help control man-caused fires around the lake.) Since shaded fuel breaks (Dell 1976, Green 1977) give only a limited amount of protection from high-intensity, fast-moving head fires, development of wider, more effective fuel modification areas is desirable where feasible. The ponderosa pine area in section 29 appears to offer this opportunity.

You take a field trip with resource people representing timber, wildlife, range, soils, water, recreation, and fire. At the site, you tour most of the area involved. Discussion then covers each resource subject, and there is a consensus that no extensive permanent damage will be done to any resource if the fire is properly prescribed and executed. Your fire personnel have conducted small burns with excellent success, and the resource staff have had a chance to evaluate effects of the burns.

Effects of the proposed prescribed burn on different resources are assessed as follows in field and office discussions:

Resource	Positive	Negative	Constraint
Soils	May warm soil as duff is reduced, increase nutrient availability; may increase pH.	Possibly increased erosion where soil is exposed; possibly reduced organic matter and soil destruction if fire is too hot.	Burn to leave lower duff on most of the area.
Water	On this site, no expected benefits.	Possibly increase turbidity and nutrients in water	If necessary, put a fireline around it; since only rock-bottomed intermittent streams are present, burn so fuel is still moist along watercourses.
Air	None except improved view of sunset.	Smoke drift into recreation or highway area.	Burning should be done in low recreation period, spring or fall.
Timber	Potential growth stimulation from nutrient release and reduced competition.	Possible loss of some trees, scarring of others; possible growth loss.	Develop gentle prescription and carefully execute fire.
Wildlife	Provide more succulent browse and forage; cause increase in some species; provide better access for large mammals.	Cause decrease in some species and a temporary decrease in browse; may lose wildlife habitat in trees and snags; may lose hiding and thermal cover.	Perhaps vary burning to give different effects; could install fireline in some areas; leave trees and snags.
Range	Provide more forage and favor more succulents; make area more accessible to livestock.	May have to let area rest for good response.	Be sure area can be isolated without affecting livestock allotments.
Recreation	Provide open vistas and accessibility in parklike stands; generally improve esthetics.	May be adverse public reaction to burning, black bark, and red needles; fire may be considered unnatural.	Gentle prescription and careful execution are important; install interpretive signs and perhaps conduct campfire sessions.

You receive tentative approval to proceed with the prescribed burn if the EAR is favorable. There are still reservations about the outcome of the burn--can the fire management group conduct the burn as they say they will?

You begin planning of the prescribed burn with a reconnaissance of the area; you combine this information with that from aerial photos and develop a good map for the burning. At the bottom of the unit, ponderosa pine dominates the vegetation; bitterbrush is the major understory plant (figs. 14 and 15). There are many interspersed pine thickets. At the top of the unit, ponderosa pine still dominates the overstory; snowbrush ceanothus and greenleaf manzanita dominate the understory (fig. 16). Large numbers of Douglas-fir and true fir seedlings and saplings are becoming established. You make notes on firelines, crew location, and possible firing patterns (fig. 17). The area has a distinct westerly aspect with slopes from 0 to 30 percent. You decide that any wind between southwest and north will be satisfactory as you can vary your lighting orientation (fig. 18). You begin filling out the prescribed burning plan (fig. 19) which serves also as a checklist of items to be done.

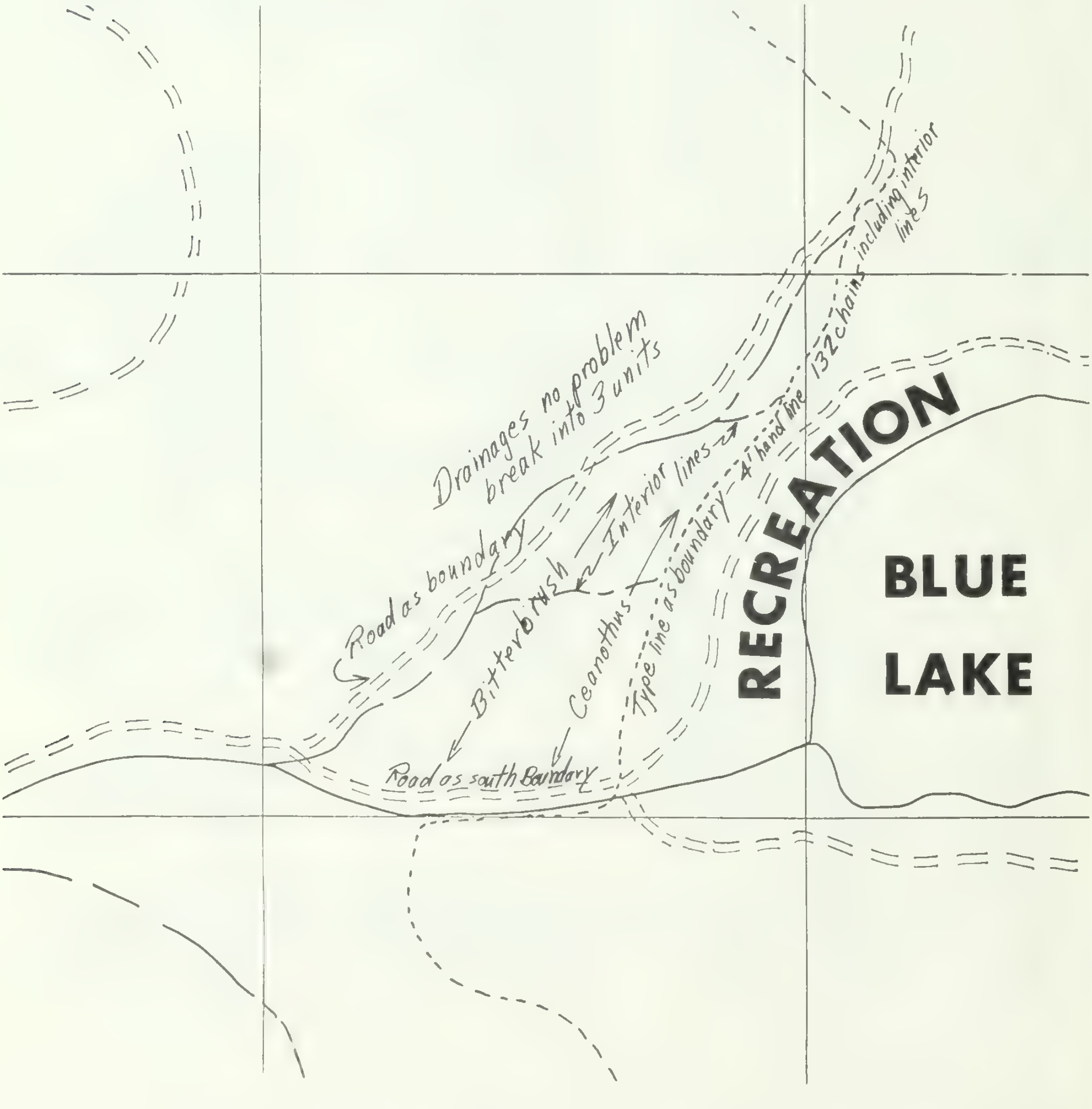

Figure 14.--Field notes on map concerning vegetation and firelines. Vegetation type line on west follows an old road along ridge, which makes construction of handline easy.

Figure 15.--Ponderosa pine with predominantly bitterbrush understory near bottom of the area. Needle drape in the bitterbrush will cause each plant to flare up; burners should be cautioned about this.

Figure 16.--Ponderosa pine with predominantly snowbrush ceanothus and greenleaf manzanita near the top of the unit. Although not visible here, true fir and Douglas-fir seedlings are becoming established.

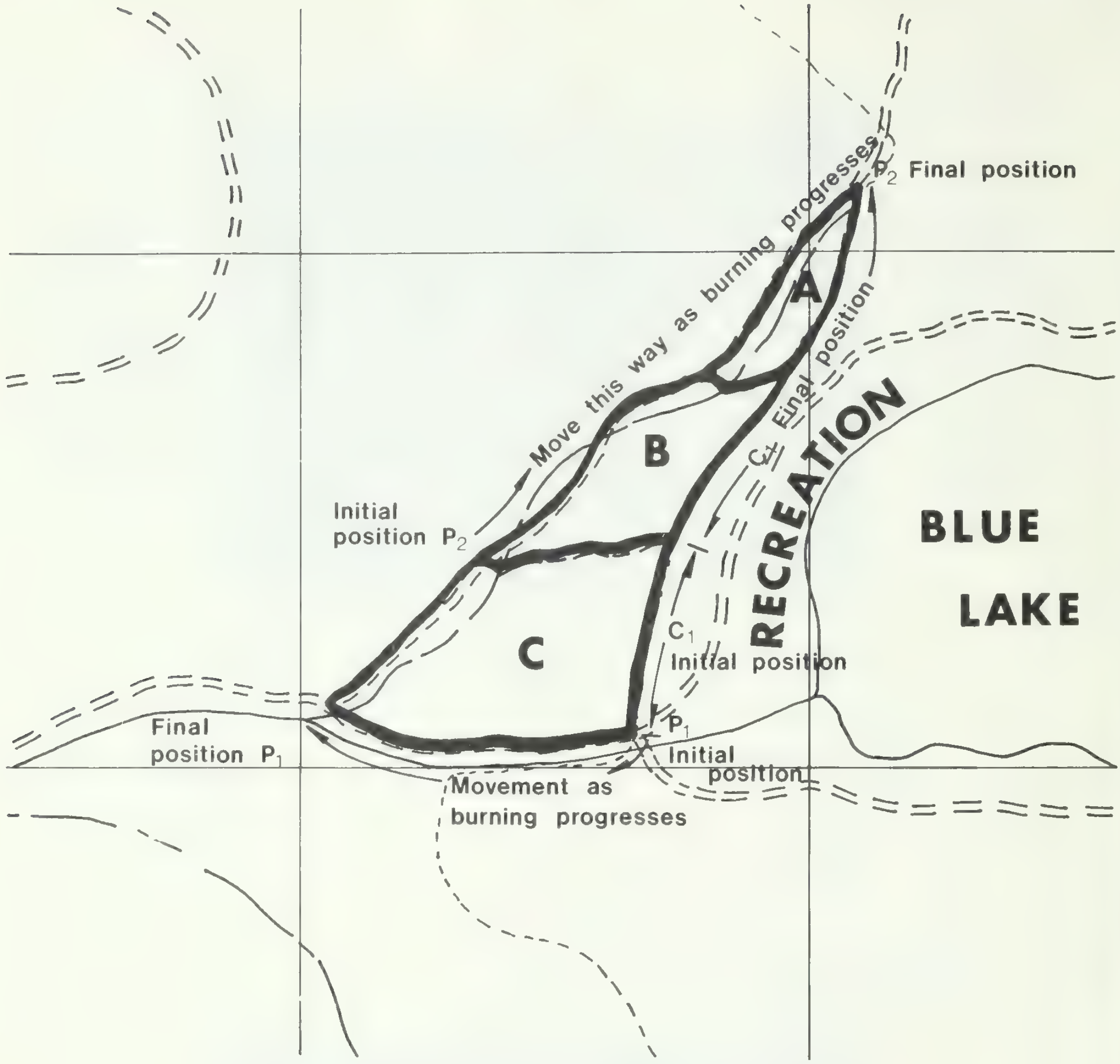

Figure 17.--Location of crews as burn progresses. Strip head fires will be used throughout the burn.

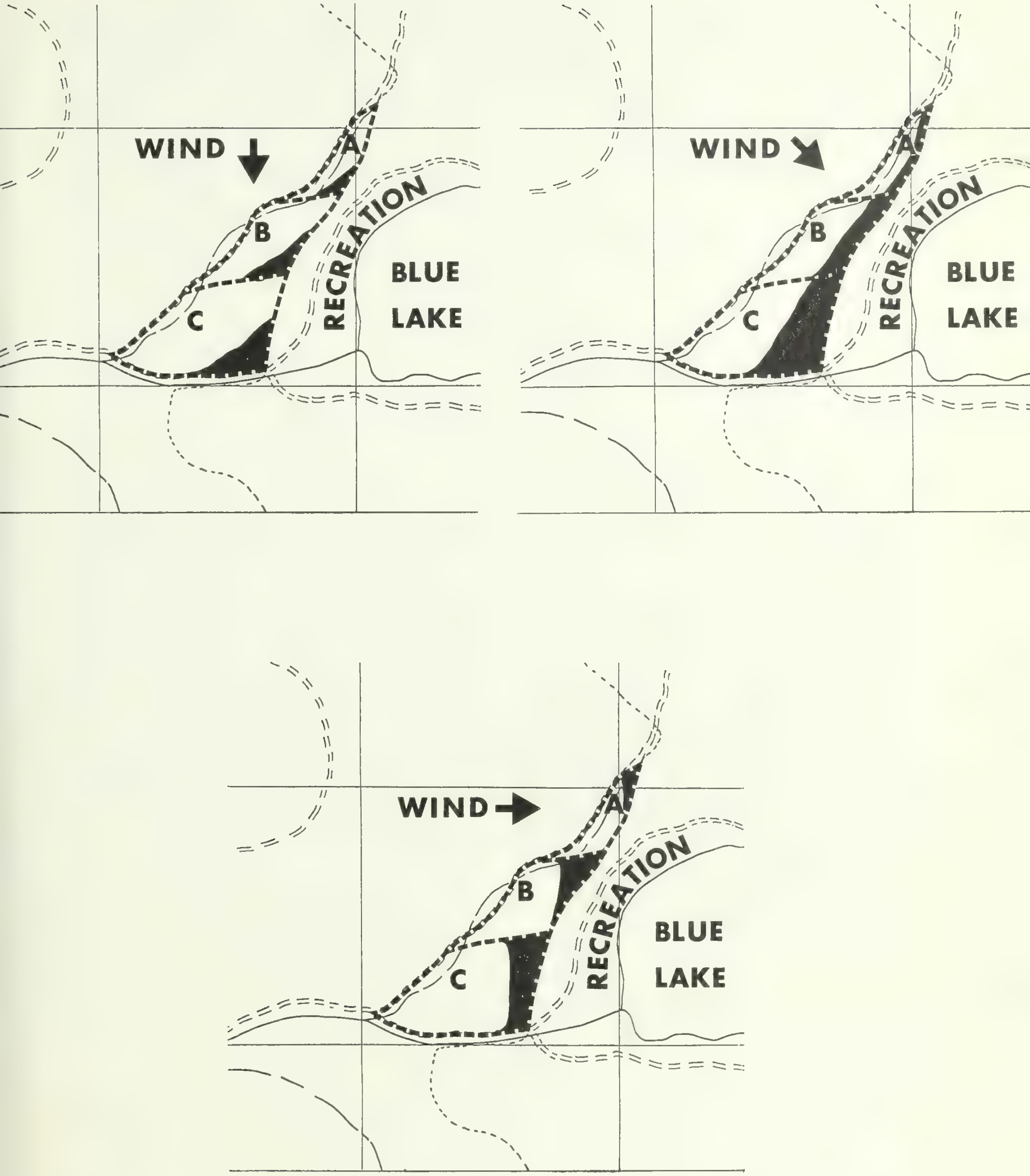

Figure 18.--A range of wind directions will satisfy prescribed burning needs. You can alter orientation of strip head fire to get satisfactory results.

SAMPLE

R6 PRESCRIBED BURNING PLAN

FOREST Dechoco	DISTRICT Appalina	FY- 1978
TRI COMPARTMENT (NAME & NUMBER)	GRID NUMBER	BURN UNIT Blue Lake
LOCATION: T 14 S, R 12 E, S 29	GROSS AREA 228 acres	NET AREA 228 acres
I&E CONTACTS KTVZ KBND, KGRL The Bend Bulletin	APPROPRIATION(S)	
	EAR PREPARED BY I.M.A. Torch	DATE

BURN AREA DESCRIPTION: DESCRIBE TREES & SHRUBS OVER 12 FEET TALL, SHRUBS & TREES UNDER 12 FEET, AND GRASSES AND FORBS (USE R6 COVER CARD #3 - ATTACH TO BURNING PLAN).

ECOCLASS CODE(S) CP-G1-11 TOPOGRAPHY ______ SLOPE 0-30% ASPECT WNW

SOIL TYPE(S) & DESCRIPTION Pumice loamy sand

FUELS (NATURAL &/OR ACTIVITY)

0 -½" SIZE CLASS 0.1-0.3 T/A SHRUBS 0.3-0.9 T/A TOTAL 9.6-15.3 T/A
½"-1" SIZE CLASS 0.3-0.8 T/A HERBACEOUS < 0.1 T/A
1"-3" SIZE CLASS 0.2-2.8 T/A DUFF ~~XXXX~~ 5.2-14.4 T/A R6 FUEL CLASSIFICATION Albini
3" + SIZE CLASS ______ T/A SURFACE FUEL DEPTH 0.5 FT NFDR FUEL MODEL K 10

MANAGEMENT GOALS OF THIS BURN

OBJECTIVES OF BURN	(CHECK)	(SPECIFICS)
HAZARD REDUCTION	x	Reduce 1,10 & 100 hr fuels to 1 ton each
SILVICULTURE	x	Kill or catface <1% of larger pine
SITE PREPARATION		
WILDLIFE HABITAT	x	Top kill 90% of shrubs; get 30% bitterbrush
RANGE MANAGEMENT		sprouting
INSECT/DISEASE CONTROL		
SPECIES MANIPULATION	x	Kill 90% of D-fir and true fir regeneration
OTHER	x	Expose <20% mineral soil

BURNING PRESCRIPTION

SEASON Fall TEMPERATURE (RANGE) 55° to 75 °F WIND DIRECTION:
TIME OF DAY PM RH (RANGE) ___ to ___ % PREFERRED W
DAYS SINCE RAIN 3-7 WIND SPEED (RANGE) 2 to 10 MPH mi/h ACCEPTABLE SW to N
FUEL MOISTURES: 1 HR TL 5-8 %, 10 HR TL 5-10 %, 100 HR TL 5+ %,
1000 HR TL 10+ %, DUFF Lower 30+%, SHRUB 50 to 100%, HERBACEOUS 50-100 %
FLAME LENGTH: MAXIMUM 5(80%) AVERAGE 3-4 FLAME HEIGHT 3 ft
ALLOWABLE SCORCH HT (FT): CROWN 20, BOLE 5 NFDR DATA: BI 50, ERC 75, IC ___, SC 5
FIRING PATTERN Strip headfire IGNITION METHOD Drip torch

LOGISTICAL INFORMATION

CHAINS LINE TO CONSTRUCT: TRACTOR ___ HAND 132 OTHER (SPECIFY) ___ TOTAL 132
CHAINS LINE TO FIRE: EXTERIOR 132 INTERIOR ___ TOTAL ___
MANPOWER NEEDS: UNIT PREPARATION 8x8 BURNING 3x8
HOLDING 8x8 MOPUP 4x8
EQUIPMENT NEEDS: UNIT PREPARATION None
BURNING None
HOLDING 3 pumpers x 8 hrs
MOPUP 2 pumpers x 8 hrs.

BURN SUMMARY

DATE BURNED ___ TIME OF DAY ___ DAYS SINCE RAIN ___ SEAS. PRECIP TO DATE ___ IN.
ACTUAL WEATHER: TEMP ___ RH ___ WIND SPEED & DIRECTION ___ NFDR BI ___
FUEL MOISTURES: 1 HR ___ 10 HR ___ 100 HR ___ 1000 HR ___ BRUSH ___ HERBACEOUS ___
FIRE BEHAVIOR: ROS ___ CH/HR, AVERAGE FLAME LENGTH ___ FT, HEIGHT ___ FT
SCORCH HEIGHT: BOLE ___ FT, CROWN ___ FT
OTHER OBSERVATIONS (If additional space is needed, use additional sheet)

PLAN PREPARED BY: I.M.A.Torch DATE
PLAN REVIEWED BY: I. M. Weried DATE
PLAN APPROVED BY: Von Bacation DATE

NOTE: ATTACH MAP OF BURN AREA

Figure 19.--The written prescribed burning plan. Maps and necessary instructions and information will be attached.

Your reconnaissance has included estimates or measurements of fuel loads. You have estimated fuel loads from photo series such as those by Maxwell and Ward (1976) or from some you have developed to meet specific needs. You have measured dead and down fuels, as well as the duff, by the planar intersect method (Brown 1974).

Before proceeding with other aspects of planning, you formulate specific objectives of the burn:

Reduce dead and down fuel loads to:

- 1 ton per acre for 1-h TL class,
- 1 ton per acre for 10-h TL class,
- 1 ton per acre for 100-h TL class,
- 2 tons per acre of duff;
- expose less than 20 percent of mineral soil;
- top-kill 90 percent of shrubs;
- obtain 30-percent sprouting of bitterbrush;
- kill or catface less than 1 percent of larger pine; and
- kill 90 percent of Douglas-fir and true fir understory in top part of burn.

Using input from several resource staff members, you prepare the EAR for the burn. Preparation and approval take some time, and it is important to get started early. Your notes from discussions with various resource people will help remind you of crucial points to cover.

Having clearly stated your objectives, you are ready to design the prescription to meet the burning objectives with the fuel loads you have measured or estimated. The final integrating factor of the prescription is the fire itself. You select a 20-foot (6-m) crown scorch height as desirable. Albini (1976, p. 65) says a 5-foot (1.5-m) flame length will give scorch heights from about 15 to 25 feet (4.6 to 7.5 m), depending on the wind. The flame length should correspond to about a 3-foot (0.9-m) flame height. You think you can hold to these flame sizes on 80 percent of the area; this would allow for occasional flareups where shrubs, saplings, or dead and down fuel concentrations ignite. You find Albini's (1976) nomograms helpful. You select Albini's model "10 Timber (Litter & Understory)" and obtain estimates of flame length, rate of spread, and fire intensity for given fuel moisture contents, windspeeds, and slopes (fig. 20). You can now write a prescription that will meet your requirements.

The prescription allows for a range of values in most variables, as some can be traded off against others to meet your objectives. You arrive at the following set of prescription variables:

- Maximum flame length, 5 feet (1.5 m), 80 percent of area
- Maximum flame height, 3 feet (0.9 m), 80 percent of area
- Maximum crown scorch height, 20 feet (6.1 m)
- 1-h TL dead fuel moisture, 5-8 percent MC
- 10-h TL dead fuel moisture, 5-10 percent MC
- 100-h TL dead fuel moisture, over 5 percent MC
- Lower duff moisture, over 30 percent MC
- Wind, 2-10 mi/h (3-16 km/h) in stand.

Your prescription is complete; you must now estimate the logistics required to prepare for and conduct the burn and to mop up afterwards. The estimates of lines to be prepared are on your field map (fig. 14). You estimate that a crew of eight

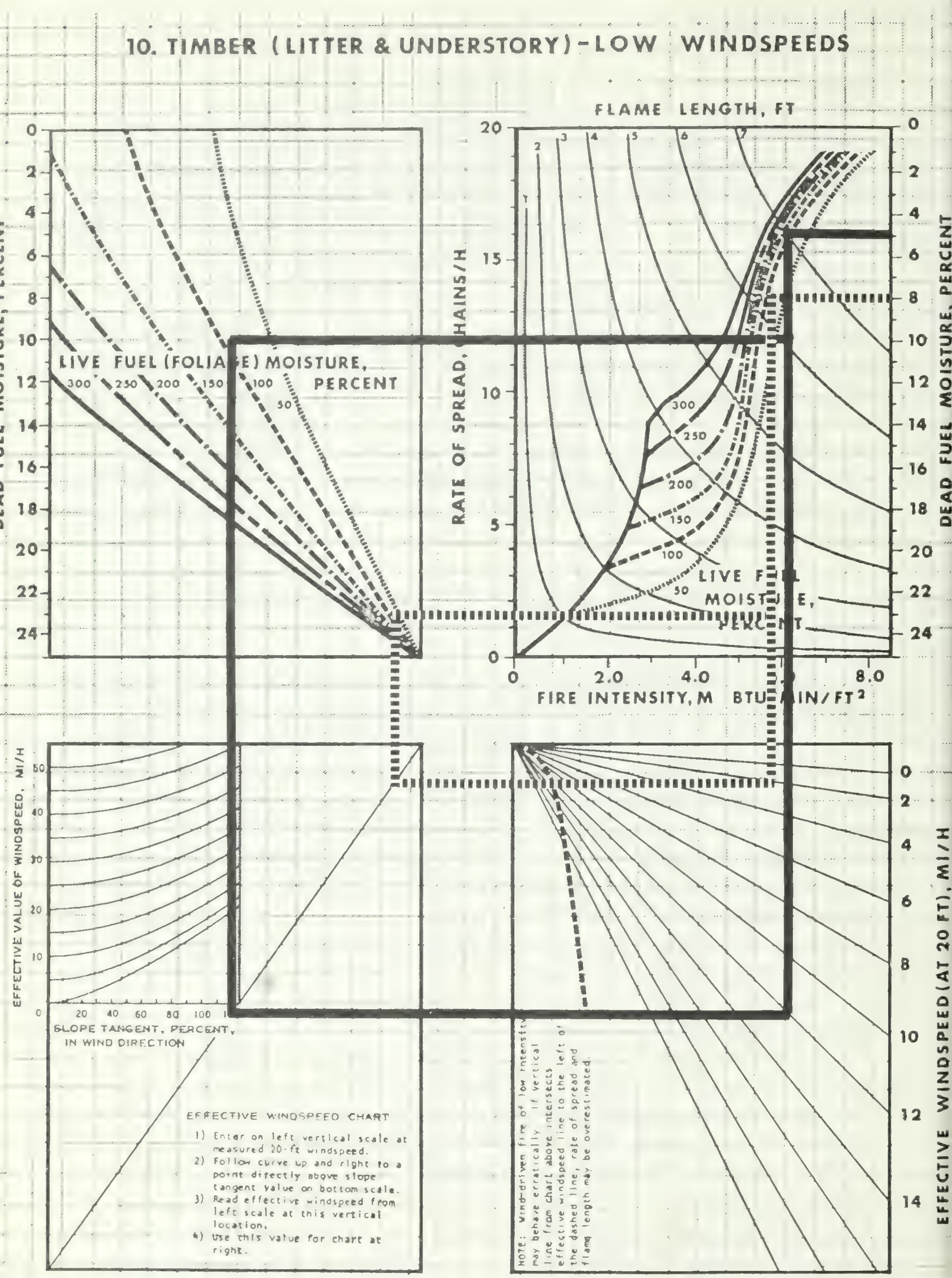

Fig. 20.--Under the least severe conditions (8-percent MC of 1-h timelag fuels, 2-mi/h (3.2-km/h) wind, and no slope), you could expect head fire flame lengths to be about 2 ft (0.6 m) and rate of spread about 1.5 chains (30 m) per hour (dashed line). Under the most severe conditions within the prescription (5-percent MC of 1-h timelag fuels, 10-mi/h (16-km/h) wind, and 30-percent slope) you could expect flame lengths of 6 ft (1.8 m) and a rate of spread of

can prepare the firelines in 1 day, since you have selected old roads and rocky drainages as firelines. You estimate your needs for burning and holding crews and for mopup. All the needed resources are entered on the burning plan.

The burning plan is essentially complete; now you need a system to monitor conditions on the site--a weather station. If you have the facilities, a dummy (temporary) NFDRS station should be installed, perhaps at a midelevation position on the site where readings can be taken daily. A hygrothermograph is good for 24-hour readings; a hygrothermoaerograph is even better (Fischer et al. 1969) for recording wind variation throughout the day and night. Each locale has its own wind peculiarities; the more you know about them, the safer will be the burning. You may supplement the weather station by using fuel moisture sticks and maximum-minimum thermometers at higher and lower elevations in the stand. As a check against predicted MC of different fuel-size classes, upper and lower duff, or foliage, you may have the weather observer collect samples for actual MC determinations. The observer can collect samples in sealed plastic bags or soil moisture cans. The samples can be transported to the office, weighed, ovendried at 160°F (70°C) for 2 to 3 days, and reweighed.[9/] (See appendix A for information on measuring moisture content.)

You are not able to prepare the area for burning this spring, so you plan for a fall burn--either a spring or fall burn could meet your prescription. You use your summer fire crews to prepare lines.

Fall arrives in mid-September. The first substantial rain falls, and measurements indicate that the burn area received 1.20 inches (3.0 cm) of rain on a Thursday. You alert all concerned parties of the possibility of burning on Monday or Tuesday, as the fire weather forecaster has predicted conditions that meet your prescription.

Weekend weather has been as predicted. On Monday morning you ask the fire weather forecaster for another spot weather forecast and then go into the field with your weather observer to check conditions on the site. The overnight low has been 40°F (5°C), and high humidity was 80 percent. Since the fire weather forecaster has predicted a high of 65° to 70°F (18° to 21°C) you quickly estimate by rule of thumb[10/] that your humidity should reach a low of 30 to 35 percent in early afternoon. (See appendix B for estimating relative humidity from temperature changes.)

You radio headquarters that you plan to begin burning at 1100. Your dispatcher has instructions for whom to contact, including not only your personnel but radio and television stations, police and sheriff's departments, and other land management agencies.

The wind, as predicted, is from the west. You assemble your crews at the southeast corner of the unit for a complete briefing of firing and holding crews. A final check with the fire weather forecaster indicates no changes in predicted weather. At 1045, notify the dispatcher you are going to "put up smoke." You light a test fire and observe its behavior. The fire backs through the duff with flames less than 1 foot (0.3 m) in length, with occasional flareups as it engulfs fuel concentrations and needle drape in the shrubs. Strip head fires burn with flame lengths

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9/ Percent moisture content is then calculated as:

$$MC\% = \frac{\text{Field weight - ovendry weight}}{\text{Ovendry weight}} \times 100.$$

Subtract the weight of the cans or bags from the field and ovendry weights before doing the calculations.

10/ Procedure based on experience and common sense.

of 1 to 3 feet (0.3 to 0.9 m) in the duff, but large shrubs with needle drape occasionally produce flame lengths of 6 to 9 feet (1.8 to 2.7 m). You explain the variation to your crewmembers and tell them what you want the fire to look like. You instruct them, as they light the strip head fires by hand, to look ahead for potential hotspots and modify their lighting to get maximum area covered but keep flame length under 5 feet (1.5 m) 80 percent of the time. When the lighters come to a potential hotspot, they should allow fire to back through the fuel where possible and should straighten the fireline on future passes.

You make the decision to continue burning and request the two lookouts in the vicinity to notify you of any major changes in the weather. You disperse the holding crews to their original stations (fig. 17).

Burning begins nicely and by 1130 approximately 3 chains (60 m) into unit C have been burned. You now begin backfiring the eastern line of unit B, at the same time dispersing six of crew C_1 along this line. At noon, you are ready to fire interior line of unit C so that you can complete that unit in the day's burning time. Pumper P_1 moves to the midpoint of the south boundary road. By 1300, you begin backfiring the east line of unit A, moving five members of crew C_1 to patrol this line. You move pumper P_2 to the north end of unit A.

You periodically check with the burners to answer questions and suggest changes in their lighting procedures. As you move through the unit you make notes on weather, fire characteristics, fuel consumption, and other factors. You are carrying out the first phases of fire evaluation. Once all fires are well into the interior of the units, you begin rotating the burners and the holding crewmembers. Two holding crewmembers at a time are designated to eat lunch but to remain on their station.

Weather readings at 1400 indicate a temperature of 64°F (18°C) and a relative humidity of 35 percent. These components look good. The wind is shifting to the northwest, and you instruct the burners to begin shifting their firing lines to a more southwest-to-northeast orientation. You also instruct the burners on unit C to extend their backfires along the south road, as this will give added protection against further wind shift from the north and allow a widened black line against which to strip head fire. You move four holding crewmembers to the south road.

By 1630, unit A is burned out, and units B and C have 5 to 7 chains (100 to 140 m) yet to burn. By now six of the holding crew and the two pumpers are mopping up hotspots along the firelines. At 1715, burning of all units is complete. You notify the dispatcher and the lookouts that burning is completed and that a pumper will patrol the area throughout the night. The pumper will continue to mopup along the firelines. A relief pumper will relieve the pumper at midnight, and a four-person crew will work with a pumper on mopup the next day.

The next morning check on mopup in the area and complete your short-term evaluation of the fire. The evaluation may be extensive, with remeasurement of fuels and documentation of tree or shrub injury, or it may be a less intensive perusal of the apparent effects of the burn. As your prescribed burning program develops, you will probably spend less time per acre in evaluation as you will be better able to estimate fire effects. You complete the evaluation section of the burning plan and plan to reevaluate in the spring and the next fall. You decide the conditions and fire will be such that after today the fire prevention technician can assess any potential problems by early morning and midafternoon visits, as well as more visits should the weather become drier and windier.

You have now completed your first management-size burn on the forest.

Summary of Steps in a Successful Prescribed Burn

1. The general objectives of management for a given piece of land should come from overall land use planning and the basic philosophy of the organization.
2. A reconnaissance is necessary to decide if the unit needs treatment. Measurements and evaluation may be needed at this point.
3. General objectives of the treatment should be developed and should involve several resource disciplines.
4. A decision should be made on the tools to be used and specific objectives of the treatment delineated. An environmental analysis report may be prepared at this point.
5. A prescription that will meet the objectives should be developed. Several estimation techniques are available.
6. Written burning plans should be developed and reviewed.
7. Preparations must be made for burning.
8. The burn is conducted.
9. The burn is evaluated and mopped up.
10. Feedback on various steps of the planning process will aid in future burning.

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Appendix A

MEASURING MOISTURE CONTENT

Moisture content (MC) in percent is defined by the equation:

$$MC, \text{ percent} = \frac{\text{Field weight - ovendry weight}}{\text{Ovendry weight}} \times 100.$$

Regardless of whether one measures the moisture content, estimates it from tables or fuel moisture sticks, or uses a moisture meter, the definition is the same. To measure fuel MC directly, we generally must collect samples and ovendry them in the laboratory.

The procedures are as follows:

1. Collect each sample to represent the size, category, and position of the fuel for which you wish to measure moisture content. Soil cans sealed with masking tape or sealed plastic bags work well. Once you have the sample, protect it and container from excess heat and sun. Each container should be identified adequately: date, time, fuel component, etc.
2. Weigh samples in container as soon as practicable after collection; if tape has been used to seal the container, first remove and discard the tape. The weight will be the field weight with tare (can or bag).
3. Ovendry the sample in the container at 160°F (70°C) for 2 days, longer if pieces of fuel are large. Until you know how long it takes, check samples each day until they reach an essentially constant weight. When the weight is constant, the sample is dry. Take only a few samples from the oven at a time, as they will pick up moisture from the air rapidly as they cool. Drying may also be done at 220°F (150°C), but some investigators think the higher temperatures may drive off volatile components, particularly in living material. Norum (1977) described use of a microwave oven to dry samples in about 30 minutes.
4. After you have obtained ovendry weight including container (tare), empty the container and weigh it to get the tare weight.
5. Subtract tare weights from the field and ovendry weights; then calculate moisture content percent by the equation above.
6. The sample recording form may be modified to fit your needs.

SAMPLE RECORDING FORM

________________ Forest ________________ District ________________ Unit

________________ Date ________________________________ Sampler

Sample description

Date and time	Can no.	Sample	Tare wt., g	Field wt. w/tare, g	Ovendry wt. w/tare, g	Field wt., g	Oven-dry wt., g	MC, per-cent
6/15/78 1400	18 C	Upper duff	77.8	188.2	175.3	110.40	97.5	13

Appendix B

ESTIMATING RELATIVE HUMIDITY AS TEMPERATURE CHANGES

This rule-of-thumb method for estimating relative humidity as the temperature changes is based on the fact that relative humidity (RH) will roughly double as the temperature drops 20°F, and will drop to one-half its previous value as the temperature increases 20°F.

Example: At 8 a.m., temperature is 40°F and RH is 84 percent.

Expected high for the day is 80°F. What will the expected low RH be?

40°F to 60°F, RH drops to 1/2 of 84% = 42%;

60°F to 80°F, RH drops to 1/2 of 42% = 21%.

Example: At 1400, temperature is 90°F and RH is 30 percent.

If temperature at 1800 is expected to be 70°F, what will RH be?

90°F to 70°F, double RH, 2 x 30% = 60%.

Steps to a successful prescribed burning program:

- Know the land management objectives
- Conduct reconnaissance and measurement
- Develop general objectives of treatment
- Decide on best tools to meet objectives
- Write specific objectives of treatment
- Estimate fire behavior for different burning conditions
- Develop prescription
- Plan and prepare carefully for burn
- Execute burn, modifying to meet objectives
- Conduct mopup as necessary
- Record evaluation of effects

If the fire is not accomplishing your objectives, modify burning. If it still does not do what you want, STOP BURNING! A prescribed fire burning in fuel that is too wet or too dry wastes resources and can lead to serious problems.

The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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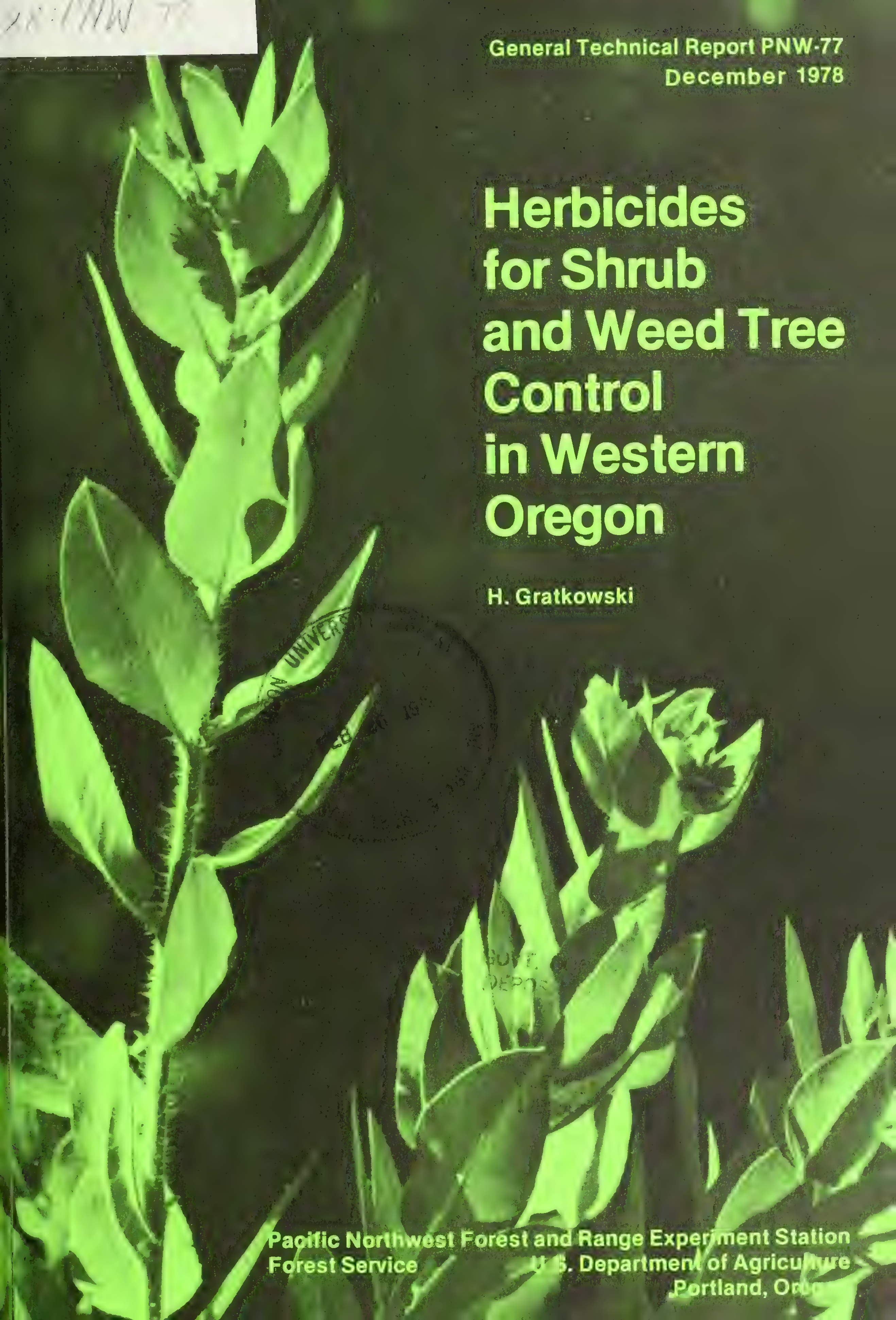
General Technical Report PNW-77
December 1978

Herbicides for Shrub and Weed Tree Control in Western Oregon

H. Gratkowski



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Abstract

Herbicides were tested on 16 common shrubs and weed trees during the past 24 years. The woody plants included snowbrush ceanothus, deerbrush ceanothus, mountain whitethorn, varnish-leaf ceanothus, sprouting and nonsprouting forms of greenleaf manzanita, hairy manzanita, hoary manzanita, golden chinkapin, golden evergreenchinkapin, Saskatoon serviceberry, Pacific madrone, salmonberry, western thimbleberry, scrub tanoak, and canyon live oak. Chemicals tested included 2,4-D, dichlorprop, 2,4,5-T, silvex, 2,4-DB, amitrole, amitrole-T, 2,3,6-TBA, AMS, picloram, Krenite™, triclopyr, and an experimental carbamate compound. Low volatile esters of 2,4-D and 2,4,5-T proved the most effective and versatile herbicides for silvicultural use in western Oregon.

Results of the screening tests are related to comparable data from small plot tests and project-scale aerial spray trials. To aid silviculturists, useful treatments and the most effective herbicide are shown in bold-face type for each shrub and weed tree.

KEYWORDS: Herbicides (-forest weed control, brush control, silviculture Oregon (western).

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach of children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: All recommendations for operational uses of pesticides were registered for such uses by the Federal Environmental Protection Agency at the time of this publication. Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

Common Measures and Metric Equivalents

1 inch	2.54 centimeters
1 foot	0.305 meter
1 mile	1.609 kilometers
1 acre	0.405 hectare
1 gallon, United States	3.785 liters
1 pound, avoirdupois	0.454 kilogram
1 pound/acre	1.121 kilograms/hectare
1 aehg or 1 aihg	0.454 kg/378.53 liters

Terms and Abbreviations

Drip point	Foliage of each plant was sprayed until all leaves had been treated and spray was running off and dripping from approximately one-half of the individual leaves.
ae	Acid equivalent; active ingredient in terms of amount of the parent acid that was converted to the amine, salt, or ester in a spray mixture or solution.
ai	Active ingredient; the amount of phytotoxic chemical compound in a spray mixture or solution.
aehg	Acid equivalent per 100 gallons of spray mixture or spray solution.
aihg	Active ingredient per 100 gallons of spray mixture or spray solution.

For additional definitions that may be useful to those using this publication, see USDA Forest Service General Technical Report PNW-37 (Gratkowski 1975), p. 39-44, "Glossary of Agricultural Chemical Terms."

Contents

Introduction

Selecting the herbicide or herbicides that will safely, effectively, and economically control shrubs or weed trees that compete with crop trees is vital in silviculture (Gratkowski 1975). Using the most effective herbicide will minimize the amount of chemical needed to attain a desired degree of brush control for site preparation or release of young conifers. It can also minimize both cost of treatment and possible environmental contamination by reducing or eliminating the need for repeated treatments that may be necessary with less effective herbicides.

This publication provides data showing effects of chemicals I have tested to control shrubs and weed trees during the past 24 years. Except for salmonberry, tabulated data are only from tests I conducted or studies in which I participated, but applicable results of other investigators are discussed in the text. This information was compiled to aid silviculturists in selecting the most effective herbicides for 16 shrub and tree species that affect silviculture in western Oregon forests. The information may also preclude additional testing of many chemicals that proved ineffective.

Screening Tests

A series of screening tests were started during 1955 to determine the effect of selected herbicides applied as foliage sprays on 13 brush species and varieties in southwestern Oregon (Gratkowski 1959). Additional tests were installed in later years as promising new herbicides became available. Some results of tests on shrubs, conifers, grasses, and forbs have been published (Gratkowski 1961, 1968, 1971, 1976, 1977). This publication supplements results of the 1955 tests with applicable data from small plot studies and project-scale trials of herbicides on native shrubs and weed trees from 1956 through 1976. Data are also provided for three species not included in the 1955 tests.

SPECIES AND STUDY AREAS

Six of the shrubs and weed trees are abundant in the southern end of the Cascade Range and eastern Oregon; 10 are common in the Coast Ranges and Siskiyou Mountains. Generally, shrubs are most difficult to control where environmental conditions are most favorable for growth. Therefore, tests on each species were installed in areas where the plants were especially large, vigorous, and abundant, indicating environmental conditions near optimum for their growth and survival. A species is much more easily controlled near the geographical limits of its range or on sites where one or more environmental factors are near a critical level for survival and growth of the species. Herbicides effective on the test areas will be even more effective on such critical sites.

Brush species and varieties[1] treated in the designated areas were:

Coast Ranges and Siskiyou Mountains

Hairy manzanita	*Arctostaphylos columbiana*
Hoary manzanita	*Arctostaphylos canescens*
Greenleaf manzanita (burled, sprouting)	*Arctostaphylos patula*
Varnishleaf ceanothus	*Ceanothus velutinus* var. *laevigatus*
Pacific madrone	*Arbutus menziesii*
Western thimbleberry	*Rubus parviflorus*
Salmonberry	*Rubus spectabilis*
Scrub tanoak	*Lithocarpus densiflorus* var. *montanus*
Canyon live oak	*Quercus chrysolepis*
Golden evergreenchinkapin	*Castanopsis chrysophylla* var. *minor*

Cascade Range

Greenleaf manzanita (no burl, nonsprouting)[2]	*Arctostaphylos obtusifolia*
Deerbrush ceanothus	*Ceanothus integerrimus*
Snowbrush ceanothus	*Ceanothus velutinus*
Mountain whitethorn	*Ceanothus cordulatus*
Golden chinkapin	*Castanopsis chrysophylla*
Saskatoon serviceberry	*Amelanchier alnifolia*

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[1] Common and scientific names are in accordance with Kelsey and Dayton (1942), except for golden chinkapin, which is in accordance with Little (1953).

[2] Although exact identity of this manzanita has not yet been established, it is the nonsprouting green-leaved manzanita prevalent in the southern end of the Cascade Range and in central Oregon. It has been variously identified as greenleaf manzanita (*Arctostaphylos patula* Greene), Howell manzanita (*A. hispidula* Howell), *A. patula* Greene ssp. *platphylla* (Gray) P.V. Wells, and as *A. obtusifolia* Piper. The nonsprouting characteristic, compared with sprouting of the burled form of greenleaf manzanita in the Siskiyou Mountains, is of special interest to foresters; this nonsprouting green-leaved manzanita can be killed more easily with herbicides at far less cost.

HERBICIDES[3/]

Thirteen chemicals were included in intensive screening tests. These were:

2,4-D	(2,4-dichlorophenoxy)acetic acid
2,4,5-T	(2,4,5-trichlorophenoxy)acetic acid
dichlorprop	2-(2,4-dichlorophenoxy)propionic acid
silvex	2-(2,4,5-trichlorophenoxy)propionic acid
2,4-DB	4-(2,4-dichlorophenoxy)butyric acid
amitrole	3-amino-1,2,4-triazole
amitrole-T	amitrole plus ammonium thiocyanate
2,3,6-TBA	A mixture of six isomers of trichlorobenzoic acid, mostly the 2,3,6-trichloro isomer
AMS	Ammonium sulfamate
picloram	4-amino-3,5,6-trichloropicolinic acid
8726-M	2,4,5-trichloro-6-nitrophenyl carbamate
triclopyr	3,5,6-trichloro-2-pyridinyloxyacetic acid
Krenite™	Ammonium ethyl carbamoylphosphonate

The chemicals were in several forms. The first four listed were low-volatile propylene glycol butyl ether esters in liquid formulations containing 4 pounds acid equivalent per gallon. 2,4-DB also was a liquid formulation containing 2 pounds of dimethyl amine per gallon. Amitrole is a fine white crystalline powder containing 50 percent active ingredient; amitrole-T is a liquid with 2 pounds active ingredient of amitrole and 2 pounds of ammonium thiocyanate per gallon. AMS was in the form of water soluble crystals, 95 percent active ingredient by weight. Picloram was tested alone as the potassium salt and as a triisopropanolamine salt in combination with similar amines of either 2,4-D alone or 2,4-D plus 2,4,5-T. 2,3,6-TBA was a water-soluble solution of the sodium salt in a formulation that contained 1.5 pounds acid equivalent per gallon. Triclopyr was tested both as a triethylamine salt and as an ethylene glycol butyl ether ester. Krenite was a liquid formulation of the active ingredient.

3/ Chemicals were provided by several companies, especially Dow Chemical U.S.A. and Amchem Products, Inc.

METHODS

Selection of herbicides and carriers was based on habit, and stem and leaf characteristics of each species; and all herbicides were applied as foliage sprays to drip point.[4/] Carriers were either water or diesel oil-in-water emulsions. Percentage of oil by volume in the spray solution is indicated in each table. All solutions and emulsions were applied as small-droplet sprays with a 3-gallon knapsack sprayer.

Phenoxy herbicides, especially 2,4-D and 2,4,5-T, were considered the most promising chemicals and given the most extensive tests in the 1955 study. They proved to be the most effective and versatile chemicals in that study and in project-scale trials and were used as standards for comparing relative effectiveness of new herbicides in subsequent screening tests.

Although most formulations were tested on 20 shrubs of each species, a few chemicals considered potentially less useful for forest brush control were screened on only 10 shrubs of selected species. The smaller tests were exploratory, but they produced useful information and are included in the tables for applicable species of shrubs and weed trees. Sprayed plants were examined in early autumn at the end of the first and second growing seasons after spraying Unless specifically noted, all tables show effect of the sprays at the end of the second growing season.

Effects of Foliage Sprays on Shrubs and Weed Trees

Effects of the herbicides on individual species and varieties are described in the pages that follow, and degree of susceptibility to herbicides is shown in parentheses for each shrub or weed tree. Species rated highly susceptible were readily killed with low concentrations of 2,4-D or 2,4,5-T in water. A rating of moderately susceptible indicates that aerial parts of the shrubs were readily killed, but most plants resprouted. A rating of resistant means that only parts of the stems and branches died back after being sprayed with herbicides; none of the treated plants were killed.

Tabulated data for many species are too extensive for quick evaluation. To aid silviculturists, I have evaluated the data and designated the best herbicide and/or treatment for each species. This information is printed in boldface type.

4/ See "Terms and Abbreviations," inside back cover.

The geographical range of each species is described briefly. Most of this information was compiled from taxonomic texts supplemented by personal knowledge of areas where I observed the species during 27 years of fieldwork. Although range data for shrubs and weed trees are incomplete, the information may assist in identifying problem brush species and choosing effective herbicides to control them.

HAIRY MANZANITA (Highly susceptible)

Hairy manzanita (fig. 1) is an erect shrub, 3 to 10 feet tall, with thick, ovate gray-green leaves 1 to 2½ inches long. Its leaves and branchlets are usually covered with long, stiff hairs, and its white flowers are in short, dense panicles. This is one of the most widespread manzanitas in the Pacific Northwest. It is abundant at low elevation on the west slope of the Cascade Range and at low to mid-elevations in the Coast Ranges from British Columbia to southern California. Hairy manzanita is especially abundant along the coast in southwestern Oregon. In all areas, this shrub usually occurs as scattered plants or in small groups interspersed with other brush species. It does not crown-sprout when the aerial parts are killed by fire or chemicals.

Figure 1.--Hairy manzanita is a common shrub in the Coast Ranges and at low elevations in the Cascade Range.

One hundred mature hairy manzanita shrubs were sprayed during mid-July 1955 in the Coast Ranges west of Roseburg, Oregon. Stems were growing and new leaves were developing. Berries were full grown but not ripe.

Hairy manzanita was easily killed with a low concentration of low volatile esters of 2,4-D in water applied as a foliage spray. 2,4-D proved more effective than 2,4,5-T on this species (Table 1).

Table 1--*Effects of herbicides on hairy manzanita at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1/]		Number	Percent	Number	Inches	Percent	Percent	
2,4-D	1	Water	20	0	0	0	100	100	Gratkowski (1959)
2,4-D	2	Water	20	0	0	0	100	100	
2,4-D	2	5% DO[2/]	20	0	0	0	100	100	
2,4,5-T	1	Water	20	0	0	0	79	65	
2,4,5-T	2	Water	20	0	0	0	100	100	

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution.

2/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

The relative value of the diesel oil emulsion compared with a water carrier could not be determined from these tests, since all treatments killed the plants. The diesel oil emulsion, however, was as effective as the water carrier and seemed to wet the pubescent foliage much more readily.

Low volatile esters of 2,4-D are recommended for foliage sprays to control hairy manzanita during the growing season. For treating individual shrubs, a 2 aehg formulation of low volatile esters in an oil-in-water emulsion carrier should prove satisfactory. Two pounds acid equivalent per acre in either water or an oil-in-water emulsion carrier should be adequate for aerial sprays on this species, which is extremely susceptible to phenoxy herbicides.

HOARY MANZANITA (Highly susceptible)

Hoary manzanita is an erect shrub, 2 to 6 feet high, with densely white-pubescent leaves and branchlets that give a gray appearance to the entire crown (fig. 2). Its range extends from southern California northward through the Coast Ranges into southwestern Oregon, where it is relatively common in the Coast Ranges, the Siskiyou Mountains, and on the west slope of the Cascade Range. Like hairy manzanita, it is usually found as individual plants or in small clumps among other

Figure 2.--Hoary manzanita shrubs 4,000 feet above sea level in the Siskiyou Mountains.

brush species; large, pure stands of this species do not seem to develop in southwestern Oregon. The shrubs do not resprout after fire or when the tops are killed with herbicide.

Both 2,4-D and 2,4,5-T were tested on hoary manzanita in the Siskiyou Mountains west of Grants Pass, Oregon. The shrubs were sprayed early in July, during their late flowering stage. Some fruits were fully developed, and new leaves were unfolding.

Hoary manzanita proved extremely susceptible to both 2,4-D and 2,4,5-T applied as foliage sprays during active growth (table 2). Within the range of dosage tested, 2,4-D was as effective as 2,4,5-T. Since 2,4-D is less expensive than 2,4,5-T, use of **2,4-D is recommended for controlling hoary manzanita.** Although this species, like other manzanitas, proved resistant to late summer aerial sprays of 2,4,5-T applied to release ponderosa pine (Gratkowski 1977), it is very susceptible to phenoxy herbicides from early spring through midsummer.

Again, relative value of an oil-in-water emulsion compared with a water carrier could not be determined from these tests. Sprays containing low concentrations of 2,4-D in either carrier killed all the sprayed plants.

Table 2--*Effects of herbicides on hoary manzanita at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1/]		Number	Percent	Number	Inches	Percent	Percent	
2,4-D	1	Water	20	0	0	0	100	100	Gratkowski (1959)
2,4-D	2	Water	20	0	0	0	100	100	
2,4-D	2	5% DO[2/]	20	0	0	0	100	100	
2,4,5-T	1	Water	20	0	0	0	97	85	
2,4,5-T	2	Water	20	0	0	0	100	100	

[1/] Pounds acid equivalent per 100 gallons of spray mixture or spray solution.

[2/] Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

GREENLEAF MANZANITA (no burl) (Highly susceptible)

A nonsprouting green-leaved manzanita (see footnote 2, page 2) without burls at the root crown is the most abundant and common manzanita on the west slope of the Cascade Range in southwestern Oregon. Extensive, relatively pure stands of the species are present at elevations of 2,500 to 5,000 feet in eastern Jackson County, but it usually occurs in mixture with other brush species. This manzanita is abundant in extensive brushfields along the crest of the Cascade Range near Mount McLoughlin, northeast of Medford. West of the crest of the Cascade Range, the shrubs attain heights of 8 to 9 feet. The green-leaved manzanita prevalent in central Oregon appears to be the same species; but the shrubs are much smaller, averaging only 2 to 4 feet in height.

As indicated above, this manzanita does not form a burl at the root crown, and tests have shown that it does not crown-sprout when the tops are cut off a few inches above the soil surface or when the stems and branches are killed with herbicides (fig. 3).

One hundred and twenty large, mature shrubs were sprayed during late July in the Cascade Range near Mount McLoughlin. The shrubs were growing, and new shoots were 2 to 3 inches long on most plants. The largest new leaves were almost full size, and new berries were full grown.

This **nonsprouting greenleaf manzanita can be killed with either 2,4-D or 2,4,5-T (table 3), but 2,4-D is more effective and economical.** Although diesel oil emulsions were not noticeably more effective than water carriers, thorough coverage seemed more easily obtained with emulsion carriers.

*Figure 3.--Remnants of a nonsprouting greenleaf manzanita (*Arctostaphylos obtusifolia*) shrub sprayed with 2,4-D more than 15 years before.*

Table 3--*Effects of herbicides on nonsprouting greenleaf manzanita in the Cascade Range at the end of the second growing season after treatment*

Treatment: Herbicide	Treatment: Concentration	Treatment: Carrier	Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
	aehg[1]		Number	Percent	Number	Inches	- - - Percent	- - -	
2,4-D	1	Water	20	0	0	0	99	85	Gratkowski (1959)
2,4-D	1	5% DO[2]	20	0	0	0	97	80	
2,4-D	2	Water	20	0	0	0	100	95	
2,4-D	2	5% DO	20	0	0	0	99	100	
2,4,5-T	2	Water	20	0	0	0	96	85	
2,4,5-T	2	5% DO	20	0	0	0	95	95	

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution.

2/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

Complete spray coverage of all foliage on the exterior of the crown is necessary; foliage missed or sprayed too lightly remains alive for years after spraying, even though the rest of the crown dies. Plants with some live foliage or stem sprouts ("flagged" plants), however, did not sprout from other stems or from roots. Thorough coverage will insure maximum top-kill and minimize or eliminate such flagging in the crowns.

A small, replicated minimum-dosage test was installed during 1956 to determine the least amount of 2,4-D required per acre to insure an acceptable degree of control for this green-leaved manzanita. Low volatile propylene glycol butyl ether esters of 2,4-D were applied on 1/100th-acre plots at rates of 1, 2, and 4 pounds ae per acre in water and in oil-in-water emulsion carriers. Observation indicated 2 to 4 pounds ae per acre would be necessary in midsummer foliage sprays.

This information was used in prescribing rates of application for a 100-acre test of aerial spraying to control manzanita on the Rogue River National Forest. Three areas were sprayed with commercial formulations of isooctyl esters of phenoxy herbicides on June 10, 1958 (Gratkowski and Anderson 1968). The herbicides were applied in oil-in-water emulsions containing 1 gallon of black diesel oil in a total of 7 gallons of spray per acre. Results (table 4) indicate that **late spring aerial application of 3 pounds ae per acre of low volatile esters of 2,4-D will insure almost complete mortality of this nonsprouting green-leaved manzanita for site preparation** in southwestern Oregon. **To release young Douglas-fir or Shasta red fir,** less complete control is acceptable; **aerial application of 2 lb ae of 2,4-D or 2,4,5-T is recommended.** Choice of either herbicide or a brushkiller mixture of the two will depend upon species composition of brushfields containing this manzanita.

In central Oregon, Dahms (1961) indicated that adequate control of the smaller shrubs can be obtained with as little as 1 pound ae of 2,4-D per acre in either water or emulsion carriers. Drier and more

Table 4--*Effect of early June aerial applications of herbicides on nonsprouting greenleaf manzanita*[1/]

Treatment		Acres	Shrubs with stem sprouts	Shrub kill	
Chemical	Pounds per acre			Aerial parts	Complete plant
	ae[2/]		- - - - - - Percentage	- - - - -	
2,4-D	2	20	26	97	74
2,4-D	4	60	4	[3/]100	96
2,4-D plus 2,4,5-T	2 / 1	20	4	[3/]100	96

[1/] From Gratkowski and Anderson (1968), USDA For. Serv. Res. Pap., PNW-72, 8 p.

[2/] Acid equivalent.

[3/] A few stem tips were alive on 2 of the 50 plants examined in each of these treatments.

critical environmental conditions in central Oregon probably are responsible for both the smaller size of the shrubs and relatively easier control.

GREENLEAF MANZANITA (with burl) (Moderately susceptible)

Sprouting greenleaf manzanita is by far the most important species of manzanita in the Coast Ranges and Siskiyou Mountains. From southwestern Oregon, its range extends southward at high elevations in the inner North Coast Ranges of California and in the Sierra Nevada to southern California. This manzanita is a major component of mixed brushfields, and extensive, relatively pure stands of the species are found on many sites.

Its importance stems not only from its wide range and abundance but also from its resistance to silvicultural control. Greenleaf manzanita forms a conspicuous burl at the root crown. When the crown of a shrub is killed by cutting, fire, or chemicals, large numbers of new sprouts develop from dormant buds in the burl (fig. 4). The burl makes silviculturally acceptable control more difficult and expensive. As a result, foresters must distinguish between this species and the nonsprouting green-leaved manzanita in the Cascade Range.

Figure 4.--Greenleaf manzanita (Arctostaphylos patula) *in the Siskiyou Mountains sprouted from burls at the root crown the year after tops of the shrubs were killed with an aerial spray of 2,4-D and 2,4,5-T.*

All chemicals listed in table 5 were tested as foliage sprays on mature greenleaf manzanita shrubs at an elevation of 4,000 feet in the Siskiyou Mountains. The shrubs were growing, new leaves were developing, and fruits were full grown but not ripe.

Table 5--*Effects of herbicides on burled (sprouting) greenleaf manzanita at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1/]		Number	Percent	Number[2/]	Inches	- - - Percent	- - -	
2,4-D	2	Water	20	70	M	5	95	15	Gratkowski (1959)
2,4-D	4	Water	20	90	M	7	96	10	
2,4-D	2	5% DO[3/]	20	75	M	2	91	20	
2,4,5-T	1	Water	20	100	M	6	89	0	
2,4,5-T	2	Water	20	100	M	7	84	0	
2,4,5-T	1	5% DO	20	95	M	5	90	5	
2,4-DB	4	Water	20	40	M	7	99	50	Previously unpublished data
AMS	20	4% DO[4/]	20	90	M	6	87	5	
8726-M	2	Water	20	100	M	6	90	0	

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for AMS read aihg (active ingredient per 100 gallons).

2/ M = number of basal sprouts equal to or more than the original number of stems at ground level.

3/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

4/ Oil-in-water emulsion carrier containing DO equivalent to 4 gallons per 100 gallons of spray mixture.

Greenleaf manzanita proved moderately resistant to foliage sprays of 2,4-D and 2,4,5-T in the initial tests. Aerial parts of the shrubs were readily killed by the phenoxy herbicides, but most shrubs produced large numbers of sprouts from buds in the burls.

As with other *Arctostaphylos* spp., low volatile esters of 2,4-D were more effective than similar esters of 2,4,5-T on this manzanita. A water carrier was as effective as an oil-in-water emulsion, but the emulsion seemed to wet the foliage more readily and thoroughly. Since 2,4-D is not only more effective but also costs less than 2,4,5-T, use of **2,4-D in a light oil-in-water emulsion is recommended for foliage sprays to control greenleaf manzanita.**

Greenleaf manzanita was the only one of five shrub species on which the dimethyl amine of 2,4-DB was more effective than low volatile esters of 2,4-D and 2,4,5-T. If additional species should prove susceptible to 2,4-DB, this chemical may have some silvicultural value. Since greenleaf manzanita was the only one of five species so susceptible to 2,4-DB, this does not seem likely and 2,4-DB cannot be considered a substitute for the phenoxyacetic herbicides 2,4-D or 2,4,5-T.

Results of tests on individual shrubs and aerial spray applications indicate that--beyond an effective minimum dosage--lower concentrations and smaller amounts of phenoxy herbicides produce better results than more concentrated sprays or greater amounts of herbicide per acre. In tests on individual shrubs (table 5), 2 lb aehg foliage sprays of phenoxy herbicides were better than 4 lb aehg sprays. And in aerial sprays (Gratkowski and Philbrick 1965), 3 pounds ae of 2,4-D per acre was more effective than a greater dosage of phenoxy herbicides (table 6). One possible explanation is that excessive rates of herbicide kill leaf tissues too rapidly, reduce photosynthesis, and thus reduce absorption and translocation of phenoxy herbicide into stems and roots, where the chemicals exert their greatest phytotoxic effect (Leonard and Crafts 1956).

Table 6--*Mortality after a midsummer aerial application of herbicides on mature greenleaf manzanita in the Siskiyou Mountains*[1/]

Treatment			Number of shrubs sampled	Plants with basal sprouts	Top-kill	Complete shrub killed
Herbicide	Pounds per acre	Carrier				
	ae[2/]			- - - - Percent - - - - - -		
2,4-D	3	Emulsion	20	70	100	30
2,4-D plus 2,4,5-T	2 + 2	Emulsion	20	85	82	15
2,4-D plus 2,4,5-T	4 + 4	Emulsion	20	100	91	0

1/ From Gratkowski and Philbrick (1965), J. For. 63:922.

2/ Acid equivalent.

DEERBRUSH CEANOTHUS (Highly susceptible)

This deciduous species of *Ceanothus* with blue to white flowers that resemble lilac is one of the most widespread shrub species in western Oregon and Washington but rare east of the Cascade Range. It grows on a variety of sites and soils in the Coast Ranges, the interior valleys, and the Cascade Range (fig. 5).

Deerbrush ceanothus is found in many brushfields on forest land and sometimes forms extensive, relatively pure stands. In the Cascade Range, it is often found intermingled with redstem ceanothus in brush-fields. Deerbrush ceanothus also occurs as underbrush in sparsely timbered areas. It is considered a good browse species and a valuable component of shrub cover on big game summer range (Sampson and Jespersen 1963). The shrubs stump-sprout after cutting (McMinn 1951) and crown-sprout after the tops are killed with herbicides.

Mature shrubs of deerbrush ceanothus in the Cascade Range were sprayed with seven different herbicides and combinations of herbicides. All chemicals were applied as foliage sprays. When treated, the shrubs were in the late flowering--early fruiting stage. Twig growth had ceased, and all leaves were fully developed.

Figure 5.--A mature deerbrush ceanothus shrub in the Cascade Range.

Of the six chemicals tested, **low volatile esters of 2,4-D are recommended for foliage sprays to control deerbrush ceanothus.** By the third summer after treatment, both phenoxy herbicides, amitrole, and 2,3,6-TBA were effective on this species. All four chemicals had killed 80 to 95 percent of the sprayed plants (table 7). The 2,4-D sprays, however, are most economical and produce a degree of control equal to that obtained with the best of the other chemicals.

In a final examination 2 years after treatment in the 1955 tests, water proved more effective than a diesel oil emulsion as a carrier for 2,4-D on deerbrush. In earlier examinations, the emulsion had appeared better.

AMS and 2,4-DB cannot be considered replacements for phenoxy herbicides on deerbrush ceanothus. Neither chemical produced an acceptable degree of control when applied as foliage sprays during the summer of 1956.

In aerial sprays to release ponderosa pine and Douglas-fir on the Willamette National Forest (Gratkowski 1977), low volatile esters of 2,4,5-T in water carriers produced excellent control of deerbrush and redstem ceanothus (*Ceanothus sanguineus* Pursh). Two pounds ae of 2,4,5-T were applied in 8 gallons of spray per acre on separate areas in March and early September. March sprays were no more effective than September sprays; both resulted in excellent control of deerbrush and redstem ceanothus. Because March application damaged and killed many young ponderosa pines, however, only late summer foliage sprays were recommended for releasing pines from brush competition.

Table 7--*Effects of herbicides on deerbrush ceanothus at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1/]		Number	Percent	Number[2/]	Inches	- - - Percent	- - -	
2,4-D	1	Water	20	70	5	8	100	80	Gratkowski (1959)
2,4-D	2	Water	20	60	6	10	100	90	
2,4-D	2	5% DO[3/]	20	45	7	14	100	80	
2,4,5-T	2	Water	20	75	4	11	100	85	
amitrole	4	Water	20	40	5	4	98	95	
2,3,6-TBA	2	Water	10	78	5	10	95	80	
2,4-D plus amitrole	1 + 4	Water	10	100	7	15	100	30	
2,4-DB	1	Water	20	65	M	13	30	0	Previously unpublished data
AMS	10	Water	20	85	M	13	99	15	
AMS	10	4% DO[4/]	20	100	M	15	94	0	

[1/] Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for amitrole and AMS, read aihg (active ingredient per 100 gallons).

[2/] Average number of basal sprouts produced by individual sprayed shrubs that resprouted after treatment. M = number of basal sprouts equal to or more than the original number of stems at ground level.

[3/] Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

[4/] Oil-in-water emulsion carrier containing DO equivalent to 4 gallons per 100 gallons of spray mixture.

SNOWBRUSH CEANOTHUS (Moderately susceptible)

Snowbrush ceanothus, often called "slick-leaf ceanothus" or "sticky laurel," is one of the most common pioneer evergreen shrub species on new burns and cuttings in the Cascade Range and on the intermountain plateau east of the Cascade Range in Oregon and Washington. It is found from coastal British Columbia southward in the Cascade Range and Sierra Nevada to central California and eastward to Colorado and South Dakota. In the Coast Ranges of California, Oregon, and Washington, and at elevations up to 3,000 feet on the west slope of the Cascade Range in Oregon, snowbrush ceanothus is replaced by varnishleaf ceanothus, which is similar in appearance.

Mature snowbrush ceanothus shrubs can be 8 to 9 feet tall on the west slope of the Cascade Range. Germination of dormant seeds in the forest soil is induced by heat of forest fires, slash burning, and to a smaller degree by solar radiation heating surface soil in which the seeds are buried. Extensive, relatively pure stands of this large, evergreen shrub are common on burns and cuttings. In addition, snowbrush is frequently a major component of mixed brushfields at mid-elevations and high elevations throughout its range. The shrubs stump-sprout when aerial parts are lopped (fig. 6) or killed by fire or chemicals, adding to the problem of silvicultural control.

Figure 6.--Sprouts of snowbrush ceanothus lopped 3 years before have again overtopped many small Douglas-firs in this area. A few of the larger trees were released and will now outgrow the brush sprouts.

Initially, five herbicides were screened on snowbrush ceanothus in the Cascade Range in southwestern Oregon. When sprayed in late July 1955, stems were growing and a few blossoms were present on the shrubs. Most of the new leaves were smaller than the older leaves.

In the 1955 tests and subsequent retreatment of sprouts (Gratkowski 1959, 1968), **low volatile esters of 2,4,5-T proved most effective and useful for controlling snowbrush ceanothus** (table 8). Although other chemicals also killed aerial parts of the shrubs, 2,4,5-T was more effective in killing roots. Crown sprouts were least abundant on shrubs sprayed with 2,4,5-T.

Other chemicals tested cannot be considered adequate substitutes for silvicultural use of 2,4,5-T on snowbrush. Dichlorprop, for example, killed a few more shrubs than 2,4,5-T; but sprouts were much more abundant on the remaining shrubs. In addition, dichlorprop is not as effective as 2,4,5-T on many other brush species. Dichlorprop, therefore, would not be as effective as 2,4,5-T in brushfields composed of many different shrub species and weed trees--a common problem in Pacific Northwest forests.

Undiluted oil carriers are not needed when phenoxy herbicides are used to control snowbrush ceanothus, even in early spring budbreak sprays, for herbicides are intercepted as foliage sprays on evergreen

Table 8--*Effects of herbicides on snowbrush ceanothus at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1/]		Number	Percent	Number[2/]	Inches	- - - Percent	- - -	
2,4-D	2	5% DO[3/]	20	85	M	20	96	20	Gratkowski (1959)
2,4-D	4	5% DO	20	90	M	19	100	20	
2,4,5-T	2	5% DO	19	80	F	18	100	30	
2,4,5-T	4	5% DO	20	75	F	18	100	40	
dichlorprop	2	5% DO	10	80	M	20	99	50	
silvex	2	5% DO	10	100	M	23	100	0	
amitrole	8	Water	10	50	F	9	32	0	
dichlorprop plus amitrole	2 / 4	Water	10	70	F	12	97	70	
2,4-DB	2	4% DO[4/]	20	65	F	18	18	0	Previously unpublished data
AMS	20	4% DO	20	95	M	13	93	5	
AMS	40	4% DO	20	55	M	14	100	45	

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for amitrol and AMS, read aihg (active ingredient per 100 gallons).

2/ M = number of basal sprouts equal to or more than original number of stems. F = number of basal sprouts less than original number of stems at ground level.

3/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

4/ Oil-in-water emulsion carrier containing DO equivalent to 4 gallons per 100 gallons of spray mixture.

species regardless of season of application. Therefore, an oil-in-water emulsion is generally used as the carrier when phenoxy herbicides are applied to control snowbrush ceanothus. An emulsion carrier is more effective than a water carrier in wetting and penetrating the hard, sticky cuticle on the evergreen leaves.

During the past 20 years, results of aerial sprays have verified that **good control of snowbrush ceanothus can be obtained with** phenoxy herbicides in oil-in-water emulsion carriers. For example, a single **budbreak aerial application of 2 lb ae per acre of low volatile esters of 2,4,5-T in an emulsion carrier containing 3/4 gallon of diesel oil in 10 gallons of spray per acre** produced an 88-percent top-kill, and 19 percent of the shrubs were dead at the end of the second summer (Gratkowski and Stewart 1976). Experience with late summer aerial sprays, however, has shown that 2,4,5-T in a water carrier can control snowbrush ceanothus enough to safely release ponderosa pines (Gratkowski 1975, 1977).

Seasonal susceptibility.--In a study of changes in susceptibility from late spring through late summer, mature snowbrush ceanothus shrubs on two areas were foliage sprayed on 10 dates starting on June 24 and ending September 15 (Gratkowski 1977). The two spray areas were located 40 miles apart on the west slope of the Cascade Range: one area was west of Crater Lake; the second was 40 miles north near Quartz Mountain. On each treatment date, 10 shrubs were sprayed to drip point with a 2 lb aehg formulation of 2,4,5-T in an oil-in-water emulsion carrier.

Snowbrush ceanothus remained highly susceptible to 2,4,5-T throughout the entire period (table 9). In addition, more than 20 years experience has shown that snowbrush is susceptible to phenoxy herbicides from budbreak in early spring throughout the growing season. Therefore, **foresters may choose any time from budbreak through late summer to control snowbrush with low volatile esters of 2,4,5-T. The season selected within this period need depend only on silvicultural objectives.**

Table 9--*Seasonal effect of low volatile esters of 2,4,5-T applied as foliage sprays to drip point on mature snowbrush ceanothus shrubs in the Cascade Range*[1/]

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed
Date of treatment	Concentration	Carrier						
	aehg[2/]		Number	Percent	Number[3/]	Inches	- - - Percent	- - -
July 1	2	1% DO[4/]	20	10	F	39	98	90
July 8	2	1% DO	20	10	M	15	98	90
July 15	2	1% DO	20	0	0	0	100	100
July 22	2	1% DO	20	0	0	0	100	100
July 29	2	1% DO	20	0	0	0	100	100
Aug. 10	2	1% DO	20	15	M	22	98	85
Aug. 20	2	1% DO	20	0	0	0	100	100
Aug. 30	2	1% DO	20	10	F	13	100	90
Sept. 15	2	1% DO	20	5	F	16	100	95

1/ From Gratkowski (1977), For. Sci. 23:2-12.

2/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution.

3/ F = number of basal sprouts less than original number of stems originating at ground level. M = number of basal sprouts equal to or more than original number of stems. 0 = none.

4/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 1 gallon per 100 gallons of spray mixture.

VARNISHLEAF CEANOTHUS (Moderately susceptible)

Although taxonomic texts usually list varnishleaf ceanothus as a Coast Range brush species, it is a common shrub at midelevations on the west slope of the Cascade Range in western Oregon. From California its range extends northward in the Coast Ranges to British Columbia. In western Oregon, varnishleaf ceanothus is abundant in the Coast Ranges, the Siskiyou Mountains, and generally at elevations up to 2,500 feet in the Cascade Range. At that elevation, it merges with snowbrush ceanothus, whose range extends across the crest of the Cascade Range to the Rocky Mountains. In the mountains between Cottage Grove and the middle fork of the Willamette River, varnishleaf ceanothus occupies sites up to 4,000 feet above sea level. Extensive, relatively pure stands of this species occupy many burns and clearcuts in the southern end of the Cascade Range.

Like snowbrush ceanothus, varnishleaf ceanothus is often called "slick-leaf ceanothus" or "sticky laurel," and many foresters make no distinction between the species (snowbrush) and the variety (varnishleaf). Unlike snowbrush, however, individual varnishleaf ceanothus shrubs can grow to a height of 20 feet with a crown diameter of 25 feet and stems exceeding 6 inches in diameter at the base. This has an important silvicultural implication. Since varnishleaf shrubs grow much taller than snowbrush, young conifers will remain suppressed beneath varnishleaf for a much longer time (Gratkowski and Lauterbach 1974). Both forms develop a large number of fast-growing stump sprouts after cutting or fire, and both crown-sprout to a limited degree after being sprayed with low volatile esters of 2,4-D or 2,4,5-T.

Susceptibility tests.--Eight different formulations of seven herbicides were applied as foliage sprays on large mature shrubs of varnishleaf ceanothus in the Siskiyou Mountains. The sprays were applied during early July when the shrubs were in full bloom, stems were growing, and some new leaves were full size.

2,4,5-T proved the most effective herbicide to control varnishleaf ceanothus (table 10). A 4 lb aehg solution in an emulsion carrier killed all aerial parts of the exceptionally large shrubs, and 70 percent of the plants treated with this formulation did not produce basal sprouts. Two years after treatment, 85 percent of the shrubs were dead (fig. 7), and only a few sprouts were found on the remaining 15 percent. No other herbicide was as effective as 2,4,5-T on varnishleaf ceanothus.

Table 10--*Effects of herbicides on varnishleaf ceanothus at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1/]		Number	Percent	Number[2/]	Inches	Percent	Percent	
2,4-D	2	5% DO[3/]	20	55	F	7	74	45	Gratkowski (1959)
2,4-D	4	5% DO	20	80	F	15	88	40	
2,4,5-T	2	5% DO	20	40	F	21	93	65	
2,4,5-T	4	5% DO	20	30	F	14	100	85	
dichlorprop	2	5% DO	10	60	F	8	60	30	
silvex	2	5% DO	10	40	F	19	88	60	
amitrole	8	Water	10	70	F	7	32	0	
dichlorprop plus amitrole	2 / 4	Water	10	50	F	7	72	50	

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for amitrol, read aihg (active ingredient per 100 gallons).

2/ F = number of basal sprouts less than original number of stems originating at ground level.

3/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

Figure 7.--Varnishleaf ceanothus shrub killed with one foliar spray of 2,4,5-T in an emulsion carrier.

Despite its large and formidable appearance, varnishleaf ceanothus sprouted far less vigorously than snowbrush after treatment with herbicides.

Seasonal susceptibility.--Exceptionally large varnishleaf ceanothus shrubs in the Coast Ranges were sprayed on nine dates between July 1 and September 16, 1960 (Gratkowski 1977). Stages of growth ranged from active growth on July 1 to no stem growth and 80 percent of the seeds disseminated on September 16. On each date, five large mature shrubs were foliage sprayed to drip point with a 2 lb aehg formulation of low volatile esters of 2,4,5-T in a 1-percent diesel oil emulsion carrier.

Varnishleaf ceanothus proved highly susceptible to 2,4,5-T throughout the entire summer season (table 11). The unusually low degree of control on July 1 may have been due to inadequate coverage of the large shrubs on the first spray date. Experience has shown that varnishleaf is as susceptible from budbreak through spring as it was throughout the summer season in this experiment.

Table 11--*Seasonal effect of low volatile esters of 2,4,5-T applied as foliage sprays to drip point on mature varnishleaf ceanothus shrubs in the Cascade Range*[1/]

Treatment			Total plants sprayed	Basal sprouts per plant, by average number and average height[2/]		Top-kill	Complete plant killed
Date of treatment	Concentration	Carrier					
	aehg[3/]		Number	Number	Inches	- - - Percent	- - -
July 1	2	1% DO[4/]	5	--	--	49	0
July 8	2	1% DO	5	--	--	96	60
July 15	2	1% DO	5	--	--	96	80
July 22	2	1% DO	5	--	--	85	60
July 29	2	1% DO	5	--	--	79	60
Aug. 10	2	1% DO	5	--	--	90	60
Aug. 20	2	1% DO	5	--	--	97	80
Aug. 30	2	1% DO	5	--	--	91	60
Sept. 16	2	1% DO	5	0	0	100	100

1/ From Gratkowski (1977), For. Sci. 23:2-12.

2/ Many of the original stems remained alive on surviving shrubs sprayed on July 1 through August 30. These expressed apical dominance and suppressed production of basal sprouts. For the September 16 sprays, no sprouts were produced because all shrubs died.

3/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution.

4/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 1 gallon per 100 gallons of spray mixture.

MOUNTAIN WHITETHORN (Moderately susceptible)

Mountain whitethorn is found in the Coast and Cascade Ranges from southern Douglas County, Oregon, southward beyond Mount Shasta in the Sierra Nevada and in the Coast Ranges to southern California. In Oregon, mountain whitethorn is common in brushfields at elevations of 3,500 feet and higher in the Siskiyou Mountains and the Coast and Cascade Ranges of southwestern Oregon (fig. 8).

Small groups of spreading, low to procumbent shrubs are typical in evergreen brushfields of the Siskiyou Mountains; extensive, relatively pure stands of taller, more erect shrubs that exceed 8 feet in height are typical on burns and cuttings in the Cascade Range. The seeds of mountain whitethorn germinate abundantly after fire (Gratkowski 1974), and relatively pure stands of this small-leaved, spiny shrub are common in broadcast-burned clearcuts on pumice soil near Diamond Lake in the Cascade Range. Mountain whitethorn produces a spreading, dense mat of roots near the soil surface and sprouts prolifically from the entire root system when the tops are cut off or killed with herbicides. This dense mat of roots probably provides seedling conifers with intense competition for soil moisture during the dry summer season.

Figure 8.--This dense stand of mountain whitethorn occupied a cutting in a Douglas-fir forest on pumice soil near the crest of the Cascade Range in southwestern Oregon.

Four herbicides were tested on mature mountain whitethorn shrubs on pumice soil in the Cascade Range. When sprayed during early August, a few late flowers were blooming on the shrubs, seed capsules were developing, and stems were growing in length on all plants.

2,4,5-T was the most effective herbicide tested on mountain whitethorn, but root kill after one application was poor even with this chemical (table 12). Basal sprouts were abundant and vigorous in all treatments. An emulsion seemed no more effective than water as a carrier for low volatile esters of 2,4-D applied as foliage sprays on this species. As with other species, however, mountain whitethorn seedlings and sprouts are more susceptible to herbicides than are vigorous, mature shrubs. Two resprays of 2,4,5-T following the initial application resulted in death of 90 percent of the shrubs (Gratkowski 1968).

When the 1955 screening tests were installed, a series of 1/100th-acre plots were also sprayed with each of the four herbicides in water at a rate of 2 pounds acid equivalent per acre (table 13). In addition, two more plots were sprayed with 2,4-D and 2,4,5-T in diesel oil emulsions. There was no replication of treatments.

Table 12--*Effects of herbicides on mountain whitethorn ceanothus at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1/]		Number	Percent	Number[2/]	Inches	- - - Percent	- - -	
2,4-D	1	Water	20	100	M	27	100	0	Gratkowski (1959)
2,4-D	2	Water	20	95	M	28	100	5	
2,4-D	1	5% DO[3/]	20	100	M	26	100	0	
2,4,5-T	2	Water	20	80	M	27	100	20	
amitrole	4	Water	19	100	M	15	88	0	
dichlorprop	2	Water	10	100	M	28	100	0	
2,4-D plus amitrole	1 / 1	Water	10	100	M	26	99	0	

[1/] Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for amitrol, read aihg (active ingredient per 100 gallons).

[2/] M = number of basal sprouts equal to or more than the original number of stems.

[3/] Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

Table 13--*Effects of herbicides on mountain whitethorn ceanothus in 1/100th-acre plots*[1/]

Treatment			Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed
Herbicide	Pounds per acre	Carrier					
	ae[2/]		Percent	Number[3/]	Inches	- - - Percent	- - -
2,4-D	2	Water	100	M	29	100	0
2,4-D	2	5% DO[4/]	100	M	28	100	0
2,4,5-T	2	Water	100	M	24	98	0
2,4,5-T	2	5% DO	90	M	23	100	10
dichlorprop	2	Water	100	M	23	98	0
amitrole	4	Water	--	-	--	5/	0

[1/] The herbicides were applied as foliage sprays in August 1955. Results were determined by examining 10 plants on each plot in October 1956.

[2/] Acid equivalent; for amitrole, read active ingredient.

[3/] M = number of basal sprouts equal to or more than the original number of stems.

[4/] Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

[5/] Little or no effect.

Results of the small plot tests verified the results of the individual plant tests. 2,4,5-T again proved more effective than the other chemicals, but sprouting occurred in all treatments. As in the tests on individual shrubs, a diesel oil emulsion was no more effective than water as a carrier for 2,4-D. The emulsion appeared slightly more effective than water as a carrier for 2,4,5-T, however.

For aerial application, low volatile esters of 2,4,5-T are recommended to control mountain whitethorn, since repeated sprays also proved 2,4,5-T more effective than 2,4-D on this species (Gratkowski 1968). Esters of 2,4-D can be used if necessary but will usually require additional applications and a higher dosage per acre to achieve the same degree of control. In an aerial application on mature shrubs in Siskiyou Mountain brushfields, however, 3 lb ae of 2,4-D per acre (table 14) resulted in top-kill of mountain whitethorn that equalled that obtained with a brushkiller mixture of 2 lb ae of 2,4-D and 2 lb ae of 2,4,5-T (Gratkowski and Philbrick 1965).

Table 14--*Mortality after a midsummer aerial application of herbicides on mature mountain whitethorn ceanothus in the Siskiyou Mountains*[1]

Treatment			Number of shrubs sampled	Plants with basal sprouts	Top-kill	Complete shrub killed
Herbicide	Pounds per acre	Carrier				
	ae[2]			- - - - - Percent	- - - - -	
2,4-D	3	Emulsion	20	100	84	0
2,4-D plus 2,4,5-T	2 + 2	Emulsion	20	100	72	0
2,4-D plus 2,4,5-T	4 + 4	Emulsion	20	100	98	0

[1] From Gratkowski and Philbrick (1965), J. For. 63:922.

[2] Acid equivalent.

PACIFIC MADRONE (Moderately susceptible)

Pacific madrone has a range that extends from Baja, California (Abrams 1951), to western British Columbia in the Coast Ranges, and from central California northward through the Sierra Nevada and Cascade Range to western Oregon. In southwest Oregon, Pacific madrone is a major component of broad sclerophyll forests and brushfields in the Siskiyou Mountains, on the eastern slope of the Coast Ranges, in the

interior valleys, and at low elevations in the Cascade Range. Broadleaved evergreen species such as tanoak, canyon live oak, chinkapin, ceanothus, and manzanita are generally found with madrone in the Siskiyou Mountains and Coast Ranges. Deciduous species such as Oregon white oak, California black oak, and poison oak are common associates at lower elevations in the dry interior valleys and in the foothills of the Cascade Range.

Esters of 2,4-D were compared with similar formulations of 2,4,5-T on tall, well-established sprouts of Pacific madrone that had developed from stumps and roots after a severe wildfire had swept the test area (Gratkowski 1977). When treated, the sprouts were 10 to 25 feet tall (fig. 9). Both herbicides were applied in water carriers as foliage sprays to drip point.

Pacific madrone appears equally susceptible to low volatile esters of 2,4-D and 2,4,5-T (table 15). **Low volatile esters of 2,4-D are recommended for foliage sprays to control madrone.** This is in agreement with Leonard and Harvey (1965), who recommend a 4 aehg formulation of 2,4-D in an oil-in-water emulsion carrier for high-volume foliage sprays to control individual plants of Pacific madrone.

Figure 9.--A clump of Pacific madrone sprouts being sprayed during a herbicide screening test.

Table 15--*Effects of herbicides on Pacific madrone at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1]		Number	Percent	Number[2]	Inches	- - - Percent	- - -	
2,4-D	2	Water	10	20	M	10	100	80	Gratkowski
2,4,5-T	2	Water	10	20	M	14	100	80	(1977)

[1] Pounds acid equivalent per 100 gallons of spray mixture or spray solution.

[2] M = number of basal sprouts equal to or more than the original number of stems.

These limited tests allowed no comparison of water vs. oil-in-water emulsion carriers, since excellent top-kill was obtained with either herbicide in a water carrier in this trial. Experience, however, indicates that oil-in-water emulsions would be more effective as a carrier for phenoxy herbicides applied as foliage sprays on thick, leathery leaves such as these, especially in low-volume aerial sprays. The added oil spreads the herbicide over the leaf surface, improves coverage, and increases penetration of herbicide through the waxy cuticle.

Seasonal susceptibility tests were also conducted to detect any change in effectiveness of esters of 2,4,5-T from the end of the growing season in late June throughout the summer until mid-September. Madrone maintained a high level of susceptibility to 2,4,5-T throughout the entire period (table 16).

Although the data from high volume spray tests (table 16) seems to indicate an increase in susceptibility and percentage of plants killed by late summer sprays, experience has shown this is not true with low-volume aerial sprays. In fact, control with low-volume, late summer aerial sprays is erratic, and many Pacific madrone trees become resistant to phenoxy herbicides during early autumn. Response varies from tree to tree, possibly a result of genetic variation controlling changes in dormancy of individual trees. Trees that become dormant sooner would be more resistant and show less effect from late summer--early autumn sprays (Gratkowski 1977).

Table 16--*Seasonal effect of low volatile esters of 2,4,5-T applied as foliage sprays to drip point on large, well-established clumps of Pacific madrone sprouts in the Rogue River Valley*[1/]

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed
Date of treatment	Concentration	Carrier						
	aehg[2/]		Number	Percent	Number[3/]	Inches	- - - Percent	- - -
June 29	2	Water	10	60	M	13	96	40
July 7	2	Water	10	60	M	12	98	40
July 13	2	Water	10	70	M	16	85	30
July 21	2	Water	10	70	M	13	97	30
July 28	2	Water	10	50	M	12	99	50
Aug. 9	2	Water	10	20	M	25	99	80
Aug. 18	2	Water	10	20	M	14	100	80
Aug. 30	2	Water	10	40	M	11	89	60
Sept. 15	2	Water	10	20	M	13	100	80

1/ This seasonal variation in response is presented graphically in For. Sci. 23:2-12 (Gratkowski 1977).

2/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution.

3/ M = number of basal sprouts equal to or more than the original number of stems.

Based on trials and experience, application of **3 lb ae per acre of low volatile esters of 2,4-D in an oil-in-water emulsion carrier is recommended for aerial sprays on relatively pure stands of Pacific madrone. Such sprays should be applied before the shrubs and trees exceed 20 feet in height.**

Reduced control must be expected in dense stands or on large trees of Pacific madrone. As with other shrubs and weed trees (Gratkowski 1968), sprays are more effective on young plants or 2- to 3-year-old sprouts of Pacific madrone than on mature trees. **In a dense stand of trees about 20 to 35 feet tall, a mixture of 2 lb ae of 2,4-D plus 1 lb ae of 2,4,5-T proved highly effective;** crowns and trunks of almost all Pacific madrone trees were killed, although many resprouted from root crowns. A repeated treatment is usually necessary on such tall trees.

SALMONBERRY (Moderately susceptible)

Salmonberry is one of the most abundant and troublesome brush species on forest land in the Coast Ranges and coastal areas of Oregon and Washington (fig. 10, A and B). Its natural range, however, is far more extensive. It occurs from Mendocino County, California, north along the coast to Alaska, and eastward in the Rocky Mountains to Idaho and Montana. Salmonberry presents special silvicultural problems at low to medium elevations on the wet coastal slopes of the Coast Ranges in Oregon and Washington and inland through the Willapa Hills to the foothills on the west slope of the Cascade Range in Washington. Dense, vigorous stands quickly occupy forest sites after logging or wildfire.

Figure 10A.--Salmonberry...

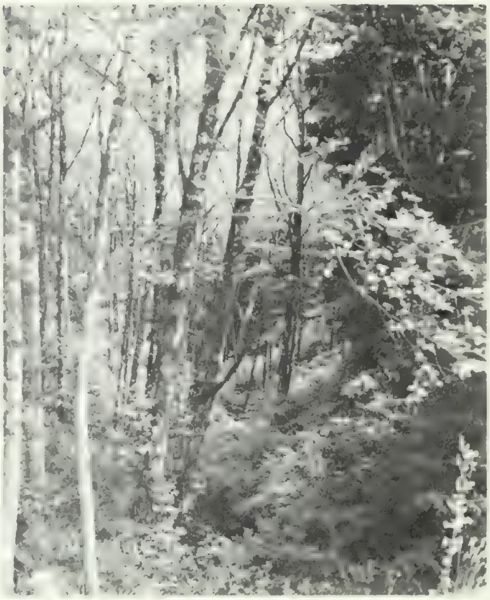

Figure 10B.--...often forms a deep, dense understory beneath red alder in the Coast Ranges.

On July 22-23, 1966, two experimental formulations of picloram (M-2951 and M-3083) were applied as foliage sprays on 1/100-acre plots of salmonberry in the Oregon Coast Ranges near Coos Bay, Oregon (Gratkowski 1971). M-2951 contained ½ lb ae of picloram plus 2 lb ae of 2,4,5-T per gallon, and M-3083 contained 1 lb each of picloram, 2,4-D, and 2,4,5-T per gallon in the form of triisopropanolamine salts. Amitrole-T and low volatile propylene glycol butyl ether esters of 2,4,5-T were applied on separate adjacent plots for comparison. A 2-percent diesel oil-in-water emulsion was used as the carrier for 2,4,5-T; the other herbicides were applied in water carriers.

In the 1966 trials, the spray solution containing 1½ lb each of triisopropanolamine salts of picloram, 2,4-D, and 2,4,5-T (M-3083) produced better control of salmonberry than any of the other treatments (table 17). Stewart (1974b) states that a single application of picloram alone may be adequate for site preparation on areas occupied by salmonberry. Piclcram, however, is nonselective and damages conifers; it cannot be used to release young conifers from salmonberry.

Table 17--*Effect of 1966 midsummer foliage sprays on salmonberry*[1/]

Herbicide	Treatment		Degree of control[2/]
	Pounds per acre	Carrier	
	aehg[3/]		
amitrole-T	2	Water	2.4
amitrole-T	2	Water	2.4
picloram	1/2	Water	2.8
2,4,5-T	2		
2,4,5-T	3	Emulsion	3.5
picloram	1	Water	3.5
2,4-D	1		
2,4,5-T	1		
picloram	1-1/2	Water	4.1
2,4-D	1-1/2		
2,4,5-T	1-1/2		

1/ From Gratkowski (1971), USDA For. Serv. Res. Note PNW-171, 5 p.

2/ A rating of 1.0 indicates little or no effect; a rating of 5.0 indicates complete kill with no resprouting.

3/ Acid equivalent per 100 gallons of spray mixture or spray solution; for amitrole-T, read aihg (active ingredient per 100 gallons).

Stewart (1974a) reported amitrole-T was more effective than 2,4,5-T in both early foliar and late foliar sprays on salmonberry, but it does not control western thimbleberry. Since most stands of salmonberry also contain thimbleberry, use of amitrole-T frequently releases thimbleberry and converts the stand to relatively pure thimbleberry. **A late foliar spray of low volatile esters of 2,4,5-T applied in an emulsion carrier controls both salmonberry and thimbleberry** (Gratkowski 1971, Stewart 1974b) and is a better choice for site preparation in plant communities where both species are important components of the shrub cover.

A late foliar aerial application of 3 lb ae of low volatile esters of 2,4,5-T is also recommended to release well established young conifers from salmonberry (Gratkowski 1971, 1975; Stewart 1974b). To release small conifers or for site preparation followed by interplanting, a second treatment with 2,4,5-T in a water carrier may be necessary to control resprouting brush and insure adequate light and soil moisture for greatest survival and height growth of the conifers.

In late July 1974, another test was installed on salmonberry to compare effects of foliage sprays of triclopyr and Krenite with effects of similar sprays of picloram and 2,4,5-T. Picloram was in the form of a potassium salt; 2,4,5-T was a low volatile ester. Krenite was a water-soluble liquid formulation of the active ingredient; triclopyr formulations were a triethylamine salt and an ethylene glycol butyl ether ester. As in the earlier test, all herbicides were applied as fine droplet foliage sprays to drip point.

Both Krenite and triclopyr (when registered) deserve consideration as foliage sprays for site preparation in relatively pure stands of salmonberry. Although both required 3-lb aehg spray solutions to produce a degree of control equal to that obtained with a 1-lb aehg spray of picloram (table 18), each chemical has some advantages over picloram.

Table 18--*Effect of 1970 midsummer foliage sprays on salmonberry at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier					
	aehg[1/]		Number	- - - - - - Percent	- - - - -		
2,4,5-T	3	3% DO[2/]	10	30	99	[3/]40	Stewart (1974a)
amitrole-T	3	Water	10	20	58	[3/]70	
picloram	1	Water	10	0	100	[3/]100	
2,4,5-T	3	2% DO[4/]	20	75	94	25	Gratkowski et al. (1978)
picloram	1	Water	20	15	94	85	
triclopyr ester	1	Water	20	67	99	33	
triclopyr amine	1	Water	20	68	90	32	
triclopyr amine	3	Water	20	5	100	95	
Krenite TM	1	Water	20	80	71	20	
Krenite	3	Water	20	25	98	75	

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for amitrole-T and Krenite, read aihg (active ingredient per 100 gallons).

2/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 3 gallons per 100 gallons of spray mixture.

3/ Plants sprayed July 1970; examined June 1972.

4/ Oil-in-water emulsion carrier containing DO equivalent to 2 gallons per 100 gallons of spray mixture.

Like picloram, triclopyr damages conifers and should only be used for site preparation. Triclopyr, however, controls both deciduous and evergreen brush species; picloram is much less effective on evergreen shrubs. In addition, triclopyr is less persistent in the soil and may allow planting of conifers sooner after application.

Krenite does not control evergreen brush, but it is effective on deciduous shrubs and weed trees. Krenite is registered for site preparation on forest land and now has SLN[5] labels for conifer release in Oregon and Washington. This herbicide should prove useful for releasing young conifers from competition of deciduous shrubs and weed trees--especially where the eye-catching "brown-out" of dead foliage characteristic of 2,4-D and 2,4,5-T is undesirable. A more complete discussion of these tests is available in a publication by Gratkowski et al. (1978).

WESTERN THIMBLEBERRY (Moderately susceptible)

Western thimbleberry may be found from southern California northward to Alaska at elevations ranging from sea level to 9,000 feet. From the west coast, its range extends eastward to New Mexico, Colorado, and Michigan. It also occupies a wide range of habitats from open to wooded, and moist to dry sites throughout Oregon and Washington. Western thimbleberry is an especially common associate of salmonberry in dense brushfields following logging, wildfire, or soil disturbance on the western slopes of the Coast Ranges in Oregon and Washington (fig. 11, A and B).

On July 22-23, 1966, two experimental formulations of picloram (M-2951 and M-3083) were applied as foliage sprays on 1/100-acre plots of thimbleberry in the Oregon Coast Ranges near Coos Bay, Oregon. M-2951 contained ½ lb ae of picloram plus 2 lb ae of 2,4,5-T per gallon, and M-3083 contained 1 lb each of picloram, 2,4-D, and 2,4,5-T per gallon. All herbicides were in the form of triisopropanolamine salts. Amitrole-T and low volatile propylene glycol butyl ether esters of 2,4,5-T were applied on separate adjacent plots for comparison.

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[5] "State and Local Need" labels issued by the respective State Departments of Agriculture as authorized by the U.S. Department of Environmental Quality.

Figure 11A.--Western thimbleberry...

Figure 11B.--...formed a dense brus cover intermixed with salmonberry on a logged area in the Oregon Coast Ranges.

Tordon 10K pellets, 10 percent ae picloram as a potassium salt, were also tested on thimbleberry at rates of 10 and 30 lb of pellets per acre. Pellets were distributed by hand; a 2-percent diesel oil-in-water emulsion was used as the carrier for 2,4,5-T; the other herbicides were applied in water carriers.

As on salmonberry, 1½ gallons of M-3083 containing 1½ lb each of picloram, 2,4-D, and 2,4,5-T per acre was more effective than any other herbicide or mixture of herbicides in the 1966 tests on western thimbleberry (table 19). Although this mixture is not registered or available, it is possible that ½ gallon per acre of Tordon 155 (½ lb ae picloram plus 2 lb ae of 2,4,5-T, both in the form of isooctyl esters) may be equally effective for site preparation in western thimbleberry. Since picloram damages conifers, Tordon 155 is not suitable for releasing young conifers overtopped by thimbleberry.

Foliage sprays of the potassium salt of picloram alone controls thimbleberry as well as salmonberry (Stewart 1974a), but it damages conifers and is used only for site preparation. Amitrole-T is relatively ineffective on western thimbleberry (Gratkowski 1971; Stewart 1974a, 1974b).

Low volatile esters of 2,4,5-T are preferred for western thimbleberry. For site preparation, control of thimbleberry by an early foliar application of 3 lb ae of 2,4,5-T in an emulsion carrier is almost equal to that obtained with a similar spray of 1 lb picloram (Stewart 1974b). In addition, esters of 2,4,5-T can be used safely for conifer release.

Table 19--*Effect of midsummer foliage sprays and picloram pellets on western thimbleberry*[1]

Herbicide	Treatment		Degree of control[2]
	Pounds per acre	Carrier	
	aehg[3]		
amitrole-T	3	Water	2
picloram pellets[4]	10	None	2
picloram pellets[4]	30	None	2
picloram 2,4,5-T	3/4 3	Water	2
2,4,5-T	3	Emulsion	4
picloram 2,4-D 2,4,5-T	1-1/2 1-1/2 1-1/2	Water	4.5

1/ From Gratkowski (1971), USDA For. Serv. Res. Note PNW-171, 5 p.

2/ A rating of 1.0 indicates little or no effect; a rating of 5.0 indicates all shrubs on the plot are dead.

3/ Acid equivalent per 100 gallons of spray mixture or spray solution; for amitrole-T, read aihg (active ingredient per 100 gallons).

4/ Picloram pellets containing 10 percent active ingredient were distributed on the soil surface throughout each plot.

As on salmonberry, **a late foliar spray of 3 lb ae of low volatile esters of 2,4,5-T in an emulsion carrier is considered the best treatment to release Douglas-fir and Sitka spruce from western thimbleberry.** The trees, however, should be protected from the spray by foliage of the brush overstory. If the trees are exposed, a water carrier should be used even though the degree of brush control will be reduced. An aerial respray may be needed 1 or 2 years later to control thimbleberry sprouts and maintain dominance of the conifers.

GOLDEN CHINKAPIN (Resistant)

Golden chinkapin is found on the west slope of the Cascade Range from the vicinity of the Columbia River southward to California and across the Cascade Range into south-central Oregon. It is abundant on the Rogue-Umpqua Divide, throughout the Siskiyou Mountains, the southern end of the Oregon Coast Ranges, and southward in the California Coast Ranges to Mendocino County.

Golden chinkapin varies greatly in habit and is often found both as a shrub and a tree in the same area (fig. 12). It is often present as understory brush in stands of conifers in the Cascade Range, where it assumes a habit intermediate between a shrub and a tree. In the understory, it grows in a clumpwise fashion similar to vine maple; each clump may develop one or more main stems resembling individual trees. Smaller stems develop on roots near the main stems to produce the clumps. Golden chinkapin trees of good form are found on many sites in both the Cascade Range and the Siskiyou Mountains.

Figure 12.--Golden chinkapin is found both as a shrub and a tree in western Oregon forests.

Eight formulations of herbicides were tested on clumps of golden chinkapin in the Cascade Range during 1955. When the shrubs were sprayed in late July, stems were still growing in length; but most of the new leaves were full size.

Sixteen months after spraying, response to all treatments was similar (table 20). All treatments affected the aerial parts to some

Table 20--*Effects of herbicides on golden chinkapin at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1]		Number	Percent	Number[2]	Inches	Percent	Percent	
2,4-D	2	5% DO[3]	20	80	M	13	38	0	Gratkowski (1959)
2,4-D	4	5% DO	20	100	M	13	54	0	
2,4,5-T	2	5% DO	20	100	M	12	61	0	
2,4,5-T	4	5% DO	20	100	M	12	61	0	
dichlorprop	2	5% DO	10	90	M	11	51	0	
silvex	2	5% DO	10	90	M	14	58	0	
amitrole	8	Water	10	40	M	6	42	0	
dichlorprop plus amitrole	2 4	Water	10	80	M	9	77	10	

[1] Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for amitrole, read aihg (active ingredient per 100 gallons).

[2] M = number of basal sprouts equal to or more than the original number of stems at ground level.

[3] Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

extent, but none were especially effective in killing roots of the sprayed plants. Great variation in top-kill within treatments indicates that there were no important differences between treatments. A few comments, however, concerning the relative effectiveness of the chemicals may be of value.

The most effective herbicide for golden chinkapin is 2,4,5-T; a conclusion verified in repeated applications on this species (Gratkowski 1968). A 2 lb aehg formulation in an emulsion carrier is recommended for foliage sprays on individual plants. In initial sprays on mature shrubs, increasing the concentration of 2,4,5-T from 2 lb aehg to 4 lb aehg did not increase its effect (table 20); evidently the 2 lb aehg dosage of 2,4,5-T was near its effective practical maximum when foliage was sprayed to drip point.

Amitrole in mixture with dichlorprop showed promise; a mixture of amitrole and dichlorprop was the most effective formulation tested. At present, however, amitrole in combination with other chemicals is not recommended for widespread use on golden chinkapin. Extensive stands of golden chinkapin do not seem to develop on forest land; it is usually intermixed with other shrubs and weed trees. Since most native shrubs and weed trees are much more susceptible to phenoxy herbicides than to amitrole, brushkiller mixtures of 2,4-D and 2,4,5-T are far more useful for controlling golden chinkapin in mixed brushfields on commercial forest land.

Aerial application of 2 lb ae of 2,4,5-T in an emulsion carrier per acre is recommended for budbreak sprays to release young conifers (except pines) from golden chinkapin. In emulsion carriers, 3/4 gallon of black diesel or No. 2 fuel oil is added in a spray volume of 10 gallons per acre. This treatment produced 81-percent top-kill, and 8 percent of the shrubs were dead in a 1973 aerial spray in the Cascade Range (Gratkowski and Stewart 1976). For specified silvicultural purposes, seasonal changes in carriers are recommended in USDA Forest Service General Technical Report PNW-37 (Gratkowski 1975).

GOLDEN EVERGREENCHINKAPIN (Resistant)

Golden evergreenchinkapin, a shrubby variety of golden chinkapin, is abundant in evergreen brushfields of the Siskiyou Mountains and sparsely distributed on the west slope of the Sierra Nevada in Eldorado County, California (fig. 13, A and B). The shrub form is generally found at higher elevations and on drier sites than golden chinkapin (McMinn 1951). It is an important component of the evergreen chaparral in southwest Oregon, and relatively pure stands are found as an open cover on many dry sites in the mountains of western Josephine County. The shrubs sprout from stumps and root crowns after fire, cutting, or treatment with herbicides.

Figure 13A.--Golden evergreen-chinkapin, a shrubby variety of golden chinkapin, is easily identified...

Figure 13B.--...by its trough-shaped leaves formed by upward folding of the blade on each side of the midrib.

Potentially useful herbicides were tested on vigorous, 5- to 15-foot-tall shrubs of golden evergreenchinkapin in three separate screening tests during 1955, 1956, 1963, and 1974. All herbicides were applied as high-volume foliage sprays during active growth, and results are presented in table 21. For comparison, effects of a single midsummer aerial spray of 2,4-D and of brushkiller mixtures of 2,4-D and 2,4,5-T on golden evergreenchinkapin in three brushfields in the Siskiyou Mountains are shown in table 22.

No herbicide killed an acceptable number of golden evergreenchinkapin shrubs after only one application as a foliage spray on well established, vigorous plants. Although some foliage, stems, and branches were killed by all herbicides, only triclopyr killed an appreciable number of golden evergreenchinkapin shrubs with one application. Amine and ester formulations of triclopyr at the highest rate (3 lb aehg) killed 25 and 45 percent of the shrubs, respectively, when applied as high volume foliage sprays. If triclopyr is later registered by EPA for forest use, it should prove useful for site preparation in mixed brushfields of evergreen and deciduous species (Gratkowski et al. 1978). Since it is nonselective and damages conifers, however, triclopyr will not be safe for conifer release.

Table 21--*Effects of herbicides on golden evergreenchinkapin at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1]		Number	Percent	Number[2]	Inches	- - - Percent	- - -	
2,4-D	2	5% DO[3]	20	100	M	12	58	0	Gratkowski (1959)
2,4-D	4	5% DO	20	100	M	11	70	0	
2,4,5-T	2	5% DO	20	100	M	10	67	0	
2,4,5-T	4	5% DO	20	100	M	10	68	0	
dichlorprop	2	5% DO	10	100	M	8	62	0	
silvex	2	5% DO	10	80	M	7	44	0	
amitrole	8	Water	10	40	F	3	61	0	
dichlorprop plus amitrole	2 / 4	Water	10	100	M	11	27	0	
2,4-DB	2	Water	20	20	M	5	2	0	Previously unpublished data
2,3,6-TBA	2	Water	20	60	F	6	9	0	
AMS	20	4% DO[4]	20	55	M	5	11	0	
AMS	40	4% DO	20	90	M	6	36	0	
picloram[5]	.5	Water	20	100	F	6	13	0	
picloram	1.0	Water	20	100	M	7	37	0	
picloram	1.5	Water	20	85	M	6	47	15	
2,4,5-T[5]	1.5	Water	20	100	M	7.	59	0	
2,4,5-T	3	2% DO[6]	20	100	M	8	81	0	Gratkowski et al. (1978)
picloram	1	Water	20	100	F	11	24	0	
triclopyr amine	1	Water	20	95	F	5	95	5	
triclopyr amine	3	Water	20	75	F	7	96	25	
triclopyr ester	3	Water	20	55	F	8	99	45	
Krenite™	1	Water	20	7/	--	--	7/	0	
Krenite	3	Water	20	7/	--	--	7/	0	

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for amitrole, AMS, and Krenite, read aihg (active ingredient per 100 gallons).

2/ M = number of basal sprouts equal to or more than original number of stems. F = number of basal sprouts less than original number of stems at ground level.

3/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

4/ Oil-in-water emulsion carrier containing DO equivalent to 4 gallons per 100 gallons of spray mixture.

5/ Picloram as potassium salt; 2,4,5-T as low volatile ester.

6/ Oil-in-water emulsion carrier containing DO equivalent to 2 gallons per 100 gallons of spray mixture.

7/ Top-kill too slight to induce basal sprouting.

Low volatile esters of 2,4,5-T are still the most reliable herbicide for silvicultural use on golden evergreenchinkapin. Since this species usually occurs with other shrubs and weed trees, 2,4,5-T is the most effective herbicide to release conifers from mixtures of golden evergreenchinkapin and other brush species. It is also effective for chemical site preparation to be followed by interplanting in understocked stands of young conifers intermixed with brush species. Treatment with 2,4,5-T will release the existing conifers, while selectively controlling and reducing competition of shrubs and weed trees to prepare the site for planting additional trees.

Table 22--*Mortality after a midsummer aerial application of herbicides on mature golden evergreenchinkapin in the Siskiyou Mountains*[1]

Treatment			Number of shrubs sampled	Plants with basal sprouts	Top-kill	Complete shrub killed
Herbicide	Pounds per acre	Carrier				
	ae[2]			Percent		
2,4-D	3	Emulsion	20	100	43	0
2,4-D plus 2,4,5-T	2 2	Emulsion	20	100	34	0
2,4-D plus 2,4,5-T	4 4	Emulsion	20	100	37	0

1/ From Gratkowski and Philbrick (1965), J. For. 63:919-923.

2/ Acid equivalent.

Increasing the concentration of 2,4,5-T beyond 2 lb aehg in an emulsion carrier did not increase either top- or root-kill of golden evergreenchinkapin (table 21). As on golden chinkapin in the Cascade Range, the 2 lb aehg dosage of 2,4,5-T in an emulsion carrier was evidently near an effective maximum for foliage sprays.

Although not as effective as triclopyr or 2,4,5-T, amitrole also controls golden evergreenchinkapin. Three applications of 4 lb aihg formulations of amitrole as foliage sprays killed 60 percent of the shrubs--a degree of control equal to that achieved with 2 lb aehg formulations of 2,4,5-T. Amitrole-T should be equally effective. Water carriers are used with either amitrole or amitrole-T. Both amitrole and amitrole-T, however, are less selective than 2,4,5-T and may damage foliage on young conifers. Therefore, amitrole-T is less desirable than 2,4,5-T for releasing young conifers from brush competition.

The mixture of amitrole and dichlorprop which looked promising on golden chinkapin in the Cascade Range was ineffective on this shrubby variety in the Siskiyou Mountains.

Oil-in-water emulsion carriers are preferred for use with phenoxy herbicides in both budbreak and late foliar sprays for site preparation and for releasing young conifers from golden evergreenchinkapin. Pines, however, are sensitive to phenoxy herbicides, especially in emulsion carriers. Water carriers should be used in late summer sprays of 2,4,5-T to release pines in southwest Oregon.

A budbreak aerial application of 3 lb ae of 2,4-D per acre in an emulsion carrier resulted in a 30-percent top-kill with 11 percent of the shrubs completely dead at the end of the second summer (Gratkowski and Stewart 1976). Young Douglas-firs were not damaged by this treatment. As with other resistant species, however, repeated aerial applications of phenoxy herbicides are required to kill more than 50 percent

of the golden evergreenchinkapin shrubs in a brushfield (Gratkowski 1968).

In two separate screening tests during 1963 and 1974, 1 lb aehg solutions of potassium salts of picloram in water applied as foliage sprays were less effective than similar treatments with low volatile esters of 2,4-D or 2,4,5-T in emulsion carriers. Picloram is not recommended for foliage sprays to control golden evergreenchinkapin.

SASKATOON SERVICEBERRY (Resistant)

Serviceberry probably has a greater range than any other shrub listed in this publication. Its range extends from Alaska southward through the Coast and Cascade Ranges to central California, thence eastward to the Dakotas, Colorado, and New Mexico. Elevational range is also great; from near sea level to subalpine areas.

Serviceberry does not form extensive, dense stands in western Oregon. Instead, it usually occurs in small clumps or scattered shrubs as a component of sparse brush understories in open stands of conifers. In dense brushfields on burns and cuttings, serviceberry shrubs are scattered throughout the stand of shrubs and weed trees. It is a substantial element of the dense 10,000-acre brushfield on the Cat Hill burn near Mount McLoughlin at the crest of the Cascade Range in southwestern Oregon.

Saskatoon serviceberry can be a severe competitor for young conifers. It produces a tangled mat of roots that fully occupy the surface layer of soil beneath dense clumps of serviceberry stems that can exceed 15 feet in height. Thick stands of sprouts develop from these root systems after fire or cutting or when the crowns are killed with herbicide.

Large clumps of serviceberry were sprayed during early August high on the west slope of the Cascade Range (fig. 14). When treated, twig growth had ceased and new buds had been formed. Most leaves were fully developed, and many of the fruits were ripe.

None of the herbicides produced a satisfactory degree of control with one treatment when applied as foliage sprays (table 23). Foliage died quickly and branches died back a limited amount, but all sprayed plants were still alive 2 years after treatment. Since all plants produced numerous stem and basal sprouts, a temporary reduction of crown size was the only result of the initial spraying. Three successive applications of phenoxy herbicides as foliage sprays were required to kill more than 50 percent of the shrubs (Gratkowski 1968).

2,4-D is recommended for use as a foliage spray to control saskatoon serviceberry. After the initial application, 2,4,5-T seemed slightly more effective than 2,4-D as a high volume foliage spray on this species. Within the

Figure 14.--The clump of serviceberry being sampled was last sprayed with 2,4-D 19 years ago. Note its greatly reduced vigor in comparison with the unsprayed shrub on right side of photo.

Table 23--*Effects of herbicides on saskatoon serviceberry at the end of the second growing season after treatment*

Treatment			Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
Herbicide	Concentration	Carrier							
	aehg[1/]		Number	Percent	Number[2/]	Inches	- - - Percent	- - -	
2,4-D	1/2	Water	20	100	M	14	33	0	Gratkowski
2,4-D	2	Water	20	100	M	11	50	0	(1959)
2,4-D	4	Water	20	100	M	14	44	0	
2,4,5-T	1/2	Water	10	100	M	15	33	0	
2,4,5-T	2	Water	10	100	M	12	68	0	
amitrole	4	Water	10	--	--	--	3/	0	
2,3,6-TBA	1	Water	10	--	--	--	3/	0	
2,4-D plus amitrole	1/2 1	Water	10	100	M	10	43	0	
2,3,6-TBA plus amitrole	1/2 1	Water	10	--	--	--	3/	0	
2,4-DB	1	Water	20	100	M	12	54	0	Previously
2,4-DB	2	Water	20	100	M	17	68	0	unpublished
AMS	10	Water	20	100	M	11	67	0	data

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for amitrole and AMS, read aihg (active ingredient per 100 gallons).

2/ M = number of basal sprouts equal to or more than original number of stems.

3/ Little noticeable effect.

range of treatments tested, however, the difference was too small to be of practical value. Use of the more expensive 2,4,5-T does not seem warranted for the slight increase in top-kill.

None of the other chemicals and combinations of chemicals tested are considered more useful than 2,4-D or 2,4,5-T on serviceberry. None were more effective than the phenoxy herbicides, and all have one or more less favorable characteristics. 2,4-DB, for example, is not effective on as wide a range of species, and AMS is less selective and corrodes spray equipment.

Probably the most important result of the tests on this species is the indication that very low concentrations of 2,4-D or 2,4,5-T may be useful for releasing conifer reproduction from competition of serviceberry. Although neither tops nor roots were entirely killed, increased light as a result of the great reduction in crown size and foliage should be beneficial to conifer reproduction. The reduction in serviceberry foliage and crown size should also increase the amount of soil moisture available to young conifers during the dry summer period.

SCRUB TANOAK (Resistant)

Scrub tanoak is another of the many undesirable evergreen shrubs on forest land in southwestern Oregon and northern California. This shrub (fig. 15) is a variety (*montanus*) of *Lithocarpus densiflorus*, one of the better hardwood trees in the Pacific Northwest. Both the tree

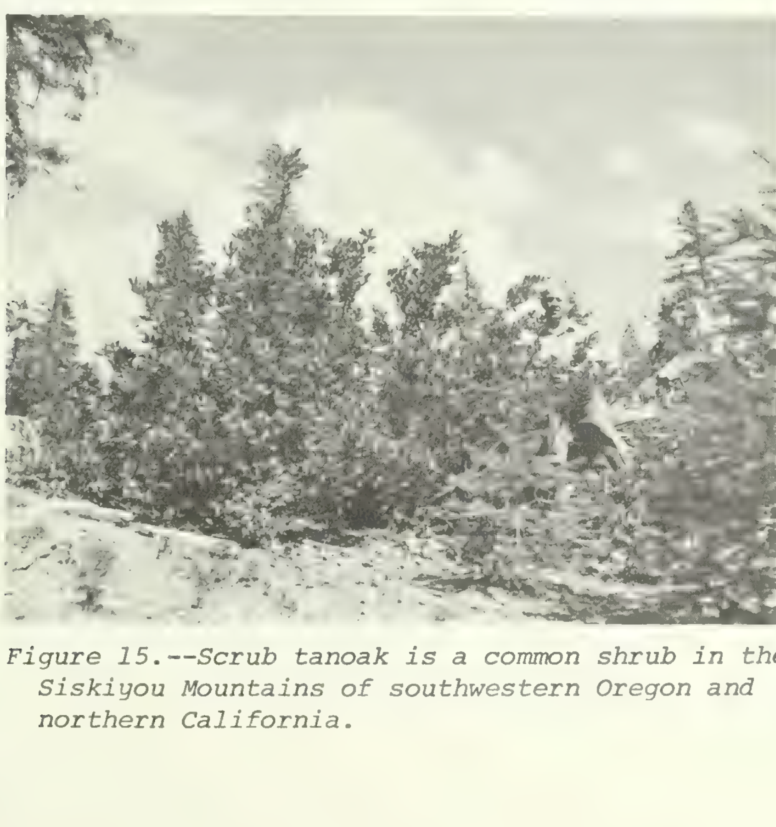

Figure 15.--Scrub tanoak is a common shrub in the Siskiyou Mountains of southwestern Oregon and northern California.

species and the shrubby variety are major components of brushfields in the Siskiyou Mountains and the interior of the Oregon Coast Ranges. In the Siskiyou Mountains near Grants Pass, scrub tanoak appears to be quite tolerant and is prevalent as an understory shrub in open stands of forest trees or in the moderate shade of partially cut stands.

One hundred and twenty plants were sprayed in the Siskiyou Mountain during mid-July 1955. The shrubs were growing, and many new leaves had attained full size. The pubescent new foliage was difficult to wet with water sprays; emulsion carriers wetted the foliage much more readily.

Scrub tanoak proved resistant to both 2,4-D and 2,4,5-T applied as foliage sprays in mid-July (table 24). Although the aerial parts died back halfway to the ground, stem sprouts developed on the living lower parts of the stems; and basal sprouts were almost invariably produced by the treated plants.

Within the range of concentrations tested, **2,4-D was as effective as 2,4,5-T** Increasing the concentration of the chemicals from 2 to 4 lb aehg in emulsion carriers did not appreciably change extent of top-kill. Evidently dosages of both 2,4-D and 2,4,5-T were already near their effective maximum when 2 lb aehg solutions were applied to drip point. The relative effectiveness of 2,4-D vs. 2,4,5-T was verified in cut surface treatments of tanoak and Pacific madrone trees in northern California

Table 24--*Effects of herbicides on scrub tanoak at the end of the second growing season after treatment*

Treatment: Herbicide	Treatment: Concentration	Treatment: Carrier	Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
	aehg[1]		Number	Percent	Number[2]	Inches	Percent	Percent	
2,4-D	2	Water	20	95	M	10	40	0	Gratkowski (1959)
2,4-D	2	5% DO[3]	20	100	M	11	66	0	
2,4-D	4	5% DO	20	100	M	14	55	0	
2,4,5-T	2	Water	20	95	M	12	43	0	
2,4,5-T	2	5% DO	20	100	M	12	58	0	
2,4,5-T	4	5% DO	20	100	M	12	63	0	

[1] Pounds acid equivalent per 100 gallons of spray mixture or spray solution.
[2] M = number of basal sprouts equal to or more than original number of stems at ground level.
[3] Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

(Radosevich et al. 1976). Amines of 2,4-D killed 87 percent and 2,4,5-T killed 79 percent of injected trees.

Diesel oil emulsions were more effective than water carriers for both 2,4-D and 2,4,5-T on scrub tanoak. Top-kill with a 2 lb aehg concentration of 2,4-D was about 65 percent greater in an emulsion carrier than in a water carrier; the effectiveness of a similar concentration of 2,4,5-T was increased almost 35 percent.

A budbreak aerial spray of 3 lb ae of 2,4-D esters in an emulsion carrier per acre killed only 3 percent of the scrub tanoak shrubs in three brushfields in the Siskiyou Mountains (Gratkowski and Stewart 1976). Top-kill on the remaining live shrubs averaged 50 percent. For comparison, foliar sprays of 2 lb and 4 lb aehg formulations of 2,4-D in emulsion carriers applied to drip point produced top-kills of 66 and 55 percent, respectively, but none of the shrubs were dead. This comparison indicates that effects of the high-volume foliage sprays shown in table 24 are reliable indicators of effects that may be expected when phenoxy herbicides are applied as low-volume aerial sprays.

Twenty years' experience with aerial sprays on scrub tanoak has verified this observation. It has also shown that repeated aerial sprays like repeated high-volume foliage sprays (Gratkowski 1968) are necessary to kill a moderately high percentage of scrub tanoak shrubs. Observation of numerous aerial spray projects also indicates that a brushkiller mixture of 2 lb ae of 2,4-D plus 1 lb ae of 2,4,5-T in an emulsion carrier is generally more effective than 3 lb ae of 2,4-D in a similar carrier on tanoak trees that have attained heights of 20 feet or more.

CANYON LIVE OAK (Resistant)

Canyon live oak, a broad-leaved evergreen shrub or tree, is a major component of brushfields in the Siskiyou Mountains and in the interior of the Coast Ranges south of the Rogue River. Low, shrubby forms of this oak are abundant in Siskiyou Mountain brushfields at elevations of 3,000 feet and above. At lower elevations, especially in canyons near Galice, it maintains its many-stemmed, shrubby characteristic but attains heights of 15 to 20 feet. The tree form is usually found in river bottoms as far north as Little River, a tributary of the North Umpqua River, east of Roseburg. From the Siskiyou Mountains, the range of canyon live oak extends southward in the Sierra Nevada to central California and in the Coast Ranges to southern California.

The low, shrubby form of canyon live oak was sprayed during mid-July in a brushfield in the Siskiyou Mountains. The shrubs averaged 4 feet in height when sprayed; twig growth had ceased, and terminal buds were forming. New leaves were similar to those of the previous year in size and appearance.

When applied as foliage sprays, neither 2,4-D nor 2,4,5-T provided an acceptable degree of control with one treatment (table 25). Although all sprayed plants were completely defoliated, top-kill was limited and every treated plant sprouted from the base (fig. 16). Stem sprouts also developed on most of the plants, but these appeared to be too few and too small to maintain life in more than a small part of the original crown.

Table 25--*Effects of herbicides on canyon live oak at the end of the second growing season after treatment*

Treatment: Herbicide	Treatment: Concentration	Treatment: Carrier	Total plants sprayed	Plants with basal sprouts	Basal sprouts per plant, by average number and average height		Top-kill	Complete plant killed	Reference cited
	aehg[1/]		Number	Percent	Number[2/]	Inches	Percent	Percent	
2,4-D	2	Water	20	100	M	9	25	0	Gratkowski (1959)
2,4-D	2	5% DO[3/]	20	100	M	7	44	0	
2,4-D	4	5% DO	20	100	M	11	54	0	
2,4,5-T	2	Water	20	100	F	6	21	0	
2,4,5-T	2	5% DO	20	100	F	5	32	0	
2,4,5-T	4	5% DO	20	100	M	8	37	0	
AMS	20	4% DO[4/]	20	95	M	5	65	0	Previously unpublished data
AMS	40	4% DO	20	100	M	5	79	0	
8726-M	2	Water	20	5/	(Only slight tip-kill, little defoliation; ineffective)				
2,4-D	3	2% DO[6/]	20	65	F	5	76	0	Gratkowski et al. (1978)
picloram	1	Water	20	30	F	5	30	0	
triclopyr amine	1	Water	20	25	F	4	64	0	
triclopyr amine	3	Water	20	25	F	4	73	0	
triclopyr ester	3	Water	20	25	F	4	78	0	
Krenite™	1	Water	20	5/	--	--	0	0	
Krenite	3	Water	20	5/	--	--	18	0	

1/ Pounds acid equivalent per 100 gallons of spray mixture or spray solution; for AMS and Krenite, read aihg (active ingredient per 100 gallons).

2/ M = number of basal sprouts equal to or more than original number of stems. F = number of basal sprouts less than original number of stems at ground level.

3/ Oil-in-water emulsion carrier containing diesel oil (DO) equivalent to 5 gallons per 100 gallons of spray mixture.

4/ Oil-in-water emulsion carrier containing DO equivalent to 4 gallons per 100 gallons of spray mixture.

5/ Top-kill too slight to induce basal sprouting.

6/ Oil-in-water emulsion carrier containing DO equivalent to 2 gallons per 100 gallons of spray mixture.

2,4-D was more effective than 2,4,5-T for killing foliage and stems of canyon live oak, but neither chemical completely killed the tops. Both chemicals were slightly more effective in the stronger (4 lb aehg) formulations than in the weaker (2 lb aehg) formulations. The increase in top-kill was so slight, however, that it did not indicate that appreciably increased control might be obtained by adding more herbicide to the spray solution; any slight increase in top-kill would not be worth the additional cost. **For high volume foliage sprays on mature canyon live oak shrubs, 3 lb aehg of 2,4-D should produce near maximum top-kill.**

A diesel oil emulsion proved more effective than a water carrier for both herbicides. With the 2 lb aehg concentration of 2,4-D, top-kill with the emulsion carrier was approximately 76 percent greater than that obtained with the water carrier. With a similar concentration of 2,4,5-T, top-kill was about 50 percent greater with the emulsion carrier.

Figure 16.--Canyon live oak sprouts on site aerial sprayed, burned, and then resprayed with a mixture of phenoxyacetic herbicides 23, 22, and 20 years before, respectively. Initially, this area was covered by a dense brushfield of evergreen shrubs.

Sprayed-and-burned shrubs of this type in Siskiyou Mountain brushfields developed broad, dense clumps of healthy sprouts from roots and root crowns that survived both the phenoxy herbicides and the fire (Gratkowski and Philbrick 1965). In many cases, these clumps contained hundreds of sprouts to replace one or two dozen stems of the original mature shrubs. It appeared impossible that any young conifer could compete and survive within the sprout clumps. Neither two additional high-volume foliage sprays on individual shrubs (Gratkowski 1968) nor two aerial resprays (table 26), however, were sufficient to kill even 50 percent of resprouting canyon live oak shrubs.

Table 26--*Mortality after a midsummer aerial application of herbicides on mature canyon live oak in the Siskiyou Mountains*[1]

Treatment			Number of shrubs sampled	Plants with basal sprouts	Top-kill	Complete shrub killed
Herbicide	Pounds per acre	Carrier				
	ae[2]			- - - - - -	Percent	- - - - - - -
2,4-D	3	Emulsion	20	100	25	0
2,4-D plus 2,4,5-T	2 + 2	Emulsion	20	100	17	0
2,4-D plus 2,4,5-T	4 + 4	Emulsion	20	100	18	0

[1] From Gratkowski and Philbrick (1965), J. For. 63:919-923.

[2] Acid equivalent.

Of all chemicals tested as high-volume foliage sprays, only 3 aehg rates of triclopyr equaled the effect of low volatile esters of 2,4-D. When registered for forest use, both ester and amine formulations of triclopyr may prove useful for site preparation (Gratkowski et al. 1978). Triclopyr, however, damages conifers and cannot be considered a replacement for 2,4-D in release sprays.

Conclusion

None of the author's screening tests of herbicides on shrubs and weed trees during the past 24 years have revealed any chemical as versatile and effective as low volatile esters of either 2,4-D or 2,4,5-T. This conclusion is in agreement with that of many others who have compared 2,4-D and 2,4,5-T with silvex, dichlorprop, dicamba, picloram, and other herbicidal chemicals on woody plants (Schubert 1962; Leonard and Harvey 1965; Stewart 1974a, 1974b). The two phenoxyacetic herbicides are effective on most shrubs and weed trees that are silvicultural problems on Pacific Northwest forest land. It must also be stressed that 2,4-D is not a suitable replacement for 2,4,5-T; nor is 2,4,5-T an acceptable replacement for 2,4-D. Although there is some overlap in effect on many brush species, the two herbicides complement rather than replace each other in silviculture.

For site preparation on areas occupied by deciduous woody plants, picloram can be a satisfactory substitute for either 2,4-D or 2,4,5-T in the forest ecosystem. Picloram, however, is more persistent than the phenoxyacetic herbicides and is not as effective on evergreen species. Newer herbicides such as glyphosate, Krenite, and triclopyr should prove useful for controlling some species and for particular silvicultural problems as indicated in the text. Tests indicate, however, that none of these can completely replace either 2,4-D or 2,4,5-T in silviculture.

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RELATIVE DENSITY: The Key to Stocking Assessment in Regional Analysis -- A Forest Survey Viewpoint

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ABSTRACT

Relative density is a measure of tree crowding compared to a reference level such as normal density. This stand attribute, when compared to management standards, indicates adequacy of stocking. The Pacific Coast Forest Survey Unit assesses the relative density of each stand sampled by summing the individual density contributions of each tree tallied, thus quantifying the effects of mixed species, mixed age, and irregular spacing on total stand density. Each tree's contribution reflects its stage of development, species, and social position. Plot clusters are designed to permit assessment of the effect of irregular spacing.

KEYWORDS: Stand density measures, stocking density.

Forest Survey is a nationwide project of the U.S. Forest Service now known officially as Renewable Resources Evaluation Research. The Portland Resources Evaluation Work Unit of the Pacific Northwest Forest and Range Experiment Station conducts the survey in California, Hawaii, Oregon, and Washington.

Contents

Introduction

Most timber inventories include stocking assessments. Stocking data are used to assess management levels, prescribe silvicultural treatment, and forecast yields. They are used to justify forestry incentive programs and to evaluate their success. Minimum stocking standards are often established by law. Despite this widespread use, opinions vary as to how stocking should be defined, measured, and interpreted.

Stocking data are useful only to the extent they answer questions of interest to the forest manager or planner. Forest Survey resource analysts use stocking data to answer specific questions about forest conditions and their implication for future timber supply. We who conduct and analyze the Forest Survey inventories of the Pacific Coast States have spent much time developing a methodology for answering analytical questions that are dependent on stocking. I believe that an account of the development of this methodology will be of interest to others. While the specifics are tailored to Forest Survey needs, the principles have broader application.

WHAT IS STOCKING ?

For many years, *Forestry Terminology* defined stocking as "...an indication of the number of trees as compared to the desirable number for best growth and management..." (Society of American Foresters 1958). Although other definitions were recently added, (Society of American Foresters 1971), this statement is the basis for the definition used in this paper: That stocking is stand density expressed as a percentage of the density of trees desired to meet a management goal.

Stocking estimation is a two-part process: first stand density is estimated; then it is compared to the desired level for a stand of that species and stage of development. Stand density may be expressed in absolute terms such as trees per acre or in relative terms "...as a coefficient, taking normal number, basal area, or volume (from yield table data) as unity..." (Society of American Foresters 1971). In the interest of clarity, I will reserve the term stand density for absolute measures and use the term relative density to describe relative measures such as percent of normal number of trees.

Relative density is the more useful of the two density measures for broad resource evaluation, since it permits comparisons of stands with differing stages of development and, sometimes, species. Normal stands, for example, have been identified and described by the authors of normal yield tables, thus making possible the comparison of the density of any stand to that of a normal stand of similar type and stage of development. The resulting ratio, expressed as a "percent of normal," measures crowding within a stand independent of its stage of development. Assuming a reasonably consistent definition of normality, density also can be compared between stands of differing type.

STOCKING NEEDS OF FOREST SURVEY

Stocking is an important ingredient both in assessments of forest condition and estimates of future timber supply. But what is a suitable stocking standard for resource analysis? To answer this question we need the ability to examine alternatives to our traditional goal of maximum wood production.

Relative density is a stand attribute while stocking is more of an analytical tool. A relative density estimate can be compared to two or more stocking standards, possibly identifying stands that are well stocked by one criterion and poorly stocked by another. In order to facilitate this type of analysis, we have refined our measure of relative density. I will briefly describe the new procedures and their development.

CHOOSING A MEASURE OF RELATIVE DENSITY

Forest Survey measures of relative density have changed over the years. In the early years, we used crown closure--a measure that was easily identified on aerial photos and correlated with timber volume. More recently, our attention has shifted from timber volume to forest condition, opportunities for silviculture treatment, and future timber supply. For these objectives, we needed a better measure of relative density--one that accounted for the effects of species, stage of development, and tree clumping on the space requirements of trees.

Curtis (1970, 1971) has compared the usual measures of relative density. All use either normal stands or open-grown trees as a point of reference. All are developed for use with even-aged, uniformly stocked stands of a single species. How can such standards be applied to uneven-aged, mixed species stands, with variable spacing? And how do we rate stands too young to be included in the yield tables?

There are no simple answers. Twenty years ago, a Society of American Foresters committee (Bickford et al. 1957) noted a lack of knowledge about how the components of tree growth are affected by variations in spacing. Today, still lacking this basic knowledge, we must make some arbitrary assumptions, remembering however, that they are assumptions--to be altered when more information becomes available.

Our Forest Survey project measures relative density by normal density--the actual number of trees per acre expressed as a percent of the number of trees in a normal stand of the same quadratic mean diameter and species. Our choice was dictated by the widespread availability of normal yield tables rather than a belief in the desirability of growing normal stands.

Although normal yield tables describe even-aged, single species stands, inventory plots frequently sample irregular stands of mixed species and age. To accommodate such stands, we developed a weighted average density standard that reflects the species and sizes of trees present (McArdle et al. 1961) in the stand. Our approach is one first used in the 1950's for the Timber Resources Review (USDA Forest Service 1958). The density contribution of each tree is calculated individually, as though it were growing in a normal stand of like trees. By knowing the density contribution of each tree, we are able to identify the contribution of each stand component, thus obtaining maximum flexibility to meet various objectives.

THE DENSITY CONTRIBUTION OF INDIVIDUAL TREES

In any stand, the water, light, and nutrients available for tree growth are limited. The contribution of an individual tree toward normal density is the share of those resources--water, light and nutrients--that would be available to it if it were growing in a normal stand. Although the share of the resource that a tree uses is best described by the development of its roots and crown, these are so difficult to measure that we have chosen more easily identifiable characteristics--stage of development, species, and crown position.

Although stage of development is frequently defined by site and age, normal stands of the same quadratic mean diameter have been found to be "...much more alike in everyway than stands of the same site and age..." (McArdle et al. 1961). Thus two stands of the same average diameter--one a young stand growing on a good site and the other an old stand growing on a poor site--are usually more similar than stands of the same site and age but differing average diameters. As a stand increases in average diameter, trees per acre decrease, thereby increasing the growing space per tree. Reineke (1933) has shown that the space occupied by average trees growing in normal stands increases exponentially with increasing quadratic mean diameter at a rate of approximately $D^{3/2}$. The exact relationship varies slightly between species.

From yield tables and yield table data, we established, for most species, the relationship between mean diameter and the average growing space available to trees growing in normal stands. Although these relationships were developed from stand data, we assumed that they account for the effect of stage of development on the area occupied by individual trees. Still unaccounted for was the effect of the tree's competitive position within the stand. We knew that a dominant tree occupies more space than an overtopped tree of the same diameter. Within an even-aged stand the relationship between a tree's diameter and the area that it occupies reflects its competitive position as well as its size, since the largest trees are dominant and the smallest are overtopped. Thus an accurate assessment of the density contribution of a single tree should recognize the combined effects of species, size, and social position.

The space occupied by individual trees growing within even-aged normal stands also varies with their diameter. Stage (1968) had shown that this space is related to the tree's diameter cubed (D^3). Curtis (1971) adds that the appropriate exponent is smaller in less dense stands, approaching $D^{3/2}$ in open stands. The reason for this difference is competition. Intermediate and suppressed trees, which occupy less space than dominants, are more common in dense stands. Thus, competitive stress accounts for the difference between the $D^{3/2}$ relationship of open stands and the D^3 relationship of dense stands.

DEVELOPING DISCOUNTS FOR CROWN POSITION

As previously explained, our relative density equations--based on the assumption that the space occupied by a tree is proportional to its diameter raised to the 3/2 power--account for the influence of stage of development on the area that a tree occupies but not for the effect of competition as indicated by a tree's social position in the stand. To determine that effect, I analyzed available plot data from approximately normal stands. After calculating the relative density (percent normality) of the plot, I partitioned this value among the trees tallied in two ways: (1) by assigning a density percent to each tally tree that was proportional to its diameter to the 3/2 power, and (2) by repeating the process with the individual density percents proportional to D^3. For these even-aged normal stands, I assumed that the D^3 relationship was the correct one. By adjusting the $D^{3/2}$ values upward or downward, depending upon crown position, I was, however, able to approximate the D^3 density values.

This suggested a system of crown class discounts to correct our equations for the effect of social position on a tree's contribution to stand density. By multiplying the density percents of dominant, codominant, and open-grown trees (with a crown ratio of 30 percent or more) by 1.1, overtopped trees by 0.4, and intermediate and thinly crowned overstory trees by 1.7, I was able to redistribute the density percents with a given stand to approximate the D^3 relationship. Another test, using different data, produced similar results. Since both tests were informal in nature and based on limited data, additional refinement of the discount values may be needed.

WHAT ABOUT SMALL TREE DENSITY?

Small tree density is a special problem, since normal yield tables seldom include trees smaller than the 2-inch (5-centimeter) class. Actually, the normality concept has little meaning in stands too young for much intraspecific competition.

Many regeneration survey designs rely on standards that reflect an anticipated density level at the time of first commercial harvest--usually a thinning--and avoid estimates of current density. This philosophy is consistent with our major objective for such stands--the prediction of future timber supply. Locally, commercial thinning is not considered feasible until the quadratic mean diameter of a

stand is at least 8 inches (20.3 centimeters). Our standard for smaller stands is the number of trees needed to achieve normality by the time such stands reach 8 inches (20.3 centimeters), with an appropriate allowance for anticipated mortality.

Since seedlings and saplings growing in an understory constitute advance regeneration, overstory and understory density are calculated separately with the understory treated as regeneration. When the overstory is heavy, the understory density is discounted for anticipated logging damage.

DETERMINING PLOT SIZE

Plot density is seldom merely the sum of density contributions from individual trees. Many stands are irregular--a mozaic of clumps and holes that have lower current productivity, greater thinning and planting needs, and a lower growth potential than evenly distributed stands. Thus we need information on tree distribution.

For years Forest Survey has measured stand density on a cluster of 10 points, each with a fixed-radius plot for small trees and a variable-radius plot for large trees. Although the design permits point-by-point analysis, a careful plot size selection is needed to insure proper measurement of cluster variability. For instance, a cluster of very small plots can indicate variability in a perfectly spaced plantation because some plots may include trees while others fall in open spaces. On the other hand, a large plot may include both clumps and holes within the plot boundary, thus hiding variation in density. We looked for a plot that was small enough to reflect density variations that affect growth, but large enough to obscure minor variations in spacing. We wanted a plot size just large enough to allow a single point to be analyzed independently, so that a single unoccupied point would indicate unutilized space and an overstocked point would indicate excessive crowding.

We made our choice by deduction. If an open-grown tree crown indicates the maximum are occupied by a tree of a given size (Krajicek et al. 1961), an appropriate plot radius would just place the tree within the plot from a point at the edge of the tree's crown. Our inventory plots are now designed to approximate this specification. Trees between 7 inches (17.78 centimeter) and 35 inches (88.9 centimeters in d.b.h. are sampled with a 30-factor (5.24 diopter) prism, and larger trees are sampled from a fixed-radius plot with a radius equal to the limiting distance of a 35-inch (88.9-centimeter) tree. Trees less than 7 inches (17.78-centimeter) in d.b.h. are tallied on a plot with a radius equal to the limiting distance of a 7-inch (17.78-centimeter) tree. This 113th-acre (0.0036-hectare) plot is large enough to assess relative density in widely spaced plantations.

AGGREGATING STAND DENSITY

Stand density data from a single point is relatively easy to analyze. Assume full-site utilization at 60 percent of normal density. If conifer density of 60 percent and less productive hardwoods add an additional 20 percent, timber yields can be increased by removing the hardwoods. Comparison with results from an earlier inventory may show that conifer density is changing--a variable input to future yield prediction.

But how do we analyze data from several points in an irregular stand? A cluster with six points at normal density and four points without trees might need both thinning and planting. Reliance on average density, however, would mislead us into thinking that the stand was just right--60 percent of normal. Or we could recalculate the average density, limiting the contribution of any single point to 60 percent (full-site occupancy). Then average density would be 36 percent--indicating that the site was underutilized but obscuring the overcrowded condition in 60 percent of the stand.

We interpret relative density point by point and aggregate answers to questions. In the stand described, six points are fully productive and four are nonproductive; thus, the stand is currently utilizing 60 percent of its productive capacity. Silvicultural treatment opportunities include thinning and, possibly, spot planting. If all points had been nonstocked at the previous inventory, then the change in productivity would be from 0 to 60 percent.

Conclusions

In uniform, even-aged, single species stands, a single relative density measure is adequate for assessing current productivity and identifying opportunities for silvicultural treatment. When tree species or sizes are mixed, the relative density of each of the stand components is needed. In stands with irregular spacing, averaging is like to obscure important information, even when relative density is broken down into stand components.

In Forest Survey, we collect information on stand irregularities by assigning a density percent to each tree tallied on a cluster of sample points. The value assigned to each tree is approximately proportional to the space that the tree would occupy, if growing in a normal stand. These relative density data depict the way in which the site is utilized by the various stand components, thus facilitating inferences about stand condition and present and future productivity. Since averaging of point data often obscures important information, analysis begins at the point level. Consequently, full use is made of the information collected.

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GPO 987-722

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Portland, Oregon 97208*

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March 1979

Average
Average
Average
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Determining Average Yarding Distance

Average
Average
Average

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Pacific Northwest Forest and Range Experiment Station
Forest Service U.S. Department of Agriculture

ABSTRACT

Emphasis on environmental and esthetic quality in timber harvesting has brought about increased use of complex boundaries of cutting units and a consequent need for a rapid and accurate method of determining the average yarding distance and area of these units. These values, needed for evaluation of road and landing locations in planning timber harvests, are easily and accurately determined by a desk-top computer and digitizer system programed in BASIC language. This paper presents two programs designed for that purpose.

KEYWORDS: Logging operations analysis/design, computer programs/programing, computers (desk-top).

METRIC EQUIVALENTS

1 foot = 0.3048 meter

1 acre = 0.4047 hectare

Contents

Introduction

Judicious planning is essential for arriving at the best means of meeting environmental and visual standards. Because of these standards, timber harvest unit boundaries have become more complex and often utilize streamside and visual buffer (leave) zones, multiple landings, and irregular shapes. These characteristics make it difficult to calculate one of the key elements affecting cost of harvesting--the average yarding distance (AYD). Calculating this variable by standard manual methods, such as combining regular geometric shapes with known AYD values or analyzing irregular shapes by numerical integration, usually becomes too laborious a procedure for practical use. Programable desk-top calculator-digitizer systems, however, provide a means for rapid and accurate determination of AYD values.

This report presents two desk-top calculator programs for obtaining unit area and average yarding distance. The first is formulated to determine the AYD for irregular harvest units under the classic assumption that logs are yarded from their location in a straight line to the landing. The desk-top calculator approach to this problem was initially described by Peters and Burke (1972). We update their document by providing a program written in the American Standard Code for Information Interchange (ASCII) BASIC language, which is common to many present-day computer systems. The second program determines AYD under the condition that logs are moved laterally to a yarding corridor and then longitudinally up the straight corridor to a landing, as with skyline systems.

Applications

Procedures were developed for determining the area and average and maximum yarding distances of timber harvest units. This information is needed for determining yarding system feasibility and cost. Good planning requires that yarding cost be combined with construction costs of access roads and landings so that the logging plan that best meets overall economic and environmental objectives can be determined.

PROGRAM 1 (AYD: NONSLACKPULLING SYSTEMS)

Program 1 applies to irregular-shaped units where the logs are yarded from their location straight to a landing. Examples of this would be cable systems not utilizing slackpulling capability (i.e., not moving logs laterally prior to moving them longitudinally to the landing), such as any high-lead system, and grapple or shotgun skyline systems operating in clearcuts.

PROGRAM 2 (AYD: SLACKPULLING SYSTEMS)

Program 2 applies to units where skyline systems with slackpulling (i.e., lateral yarding) capability operate in either parallel or fan-shaped settings. These systems would generally be required for skyline yarding of harvest cuts where residual timber is to be protected. The more versatile slackpulling systems are also used in clearcuts

and, indeed, may be required if tailholds are widely spaced or if economic analysis shows that increasing the lateral yarding distance is less costly than making more frequent rigging changes. Program 2 can accommodate one or two leave strips (unharvested areas) between the unit's rear boundary and the landing.

Program 2 could also be used for a more detailed breakdown of ground skidding where lateral yarding to the skid road is done by pulling out the winch line. The program could be manipulated to stage process all the approximately straight skid road tangents in progression to the landing. Some hand calculations would be required but most of the lengthy numerical processing would be performed within the program. This high a degree of analysis, however, is seldom practical or justified for ground skidding, and use of program 1 would generally be faster.

Problem Formulation

Matthews (1942) calculated AYD by the method of equal areas. Although this method had been used for many years, Lysons and Mann (1965) showed that it gave incorrect results for circular cutting units or segments thereof. Their analysis showed that AYD is given by:

$$\text{AYD} = \frac{\int y\,dA}{\int dA} = \frac{\text{First moment of area}}{\text{Area}}$$

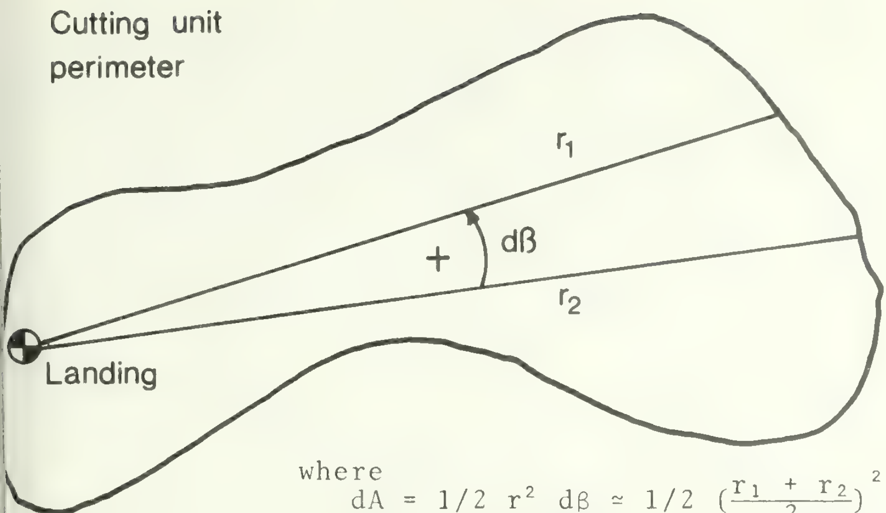
Suddarth and Herrick (1964) also derived equation 1 and developed algebraic formulas to solve AYD for the special cases of right triangles, rectangles, and circular arcs. They also derived the equation for AYD of a composite area of simple shapes, for which the respective AYD's are known. Suddarth and Herrick recommended numerical integration for complex areas.

Formulation of BASIC language programs for desk-top calculators, using the appropriate combination of these methods, provides a fast and accurate means of solving the maximum and average yarding distances and the area of a harvest unit of any shape with the landing at any location.

PROGRAM 1 (AYD: NONSLACKPULLING SYSTEMS)

Two assumptions relate to program 1: The timber is uniformly distributed over the harvest unit, and the yarding distance of each turn is equal to the shortest distance from the pickup point to the landing. These assumptions present obvious limitations when the logs are yarded over indirect routes or when there is great imbalance in timber density. For a discussion of assumptions, see Suddarth and Herrick (1964).

The programed algorithm, based on equation 1, sums the areas and moments of areas of the aggregate number of small circular arcs constituting a cutting unit:



where

$$dA = 1/2\ r^2\ d\beta \simeq 1/2\ \left(\frac{r_1 + r_2}{2}\right)^2\ d\beta;$$

$$dM = (2/3\ r)\ dA = 1/3\ r^3\ d\beta \simeq 1/3\ \left(\frac{r_1 + r_2}{2}\right)^3\ d\beta;$$

$$M = \Sigma_A\ dM;$$

$$A = \Sigma_A\ dA;$$

and

$$AYD = \frac{M}{A}.$$

ROGRAM 2 (AYD: SLACKPULLING SYSTEMS)

Operational features and assumptions relating to program 2 can be ore easily understood after figure 1 is studied. They are: (1) the imber is uniformly distributed over the harvest unit; (2) a line which passes through the midpoint between adjacent landings and the idpoint between the ends of adjacent skyline corridors) divides the irding area tributary to each skyline corridor; (3) the front and ear boundaries of any area tributary to a skyline corridor consist f lines perpendicular to the corridor which intersect the dividing lnes; (4) the unbounded exterior sides of the first and the last syline corridor are symmetrical to the bounded interior sides of these corridors; and (5) the timber is laterally yarded in a route rpendicular to the skyline corridor and longitudinally yarded along the corridor to the landing.

Figure 1 also illustrates how the boundary of an actual cutting it may vary from the programed assumptions. The net error caused this variation would normally be small because calculated excesses one side of the corridor tend to cancel deficits on the opposite de. A larger error is possible if the user is careless in laying t the first or the last corridor. If these corridors are positioned e third of the distance between the lateral unit boundary and the frst interior corridor, this error is minimized. Good layout would tnd toward this positioning anyway, as it balances the required lteral yarding.

The dividing line feature of this program implies that logs are to laterally yarded to the nearest corridor. In portions of some its, however, this is not the practice. Where steep slopes perpen-

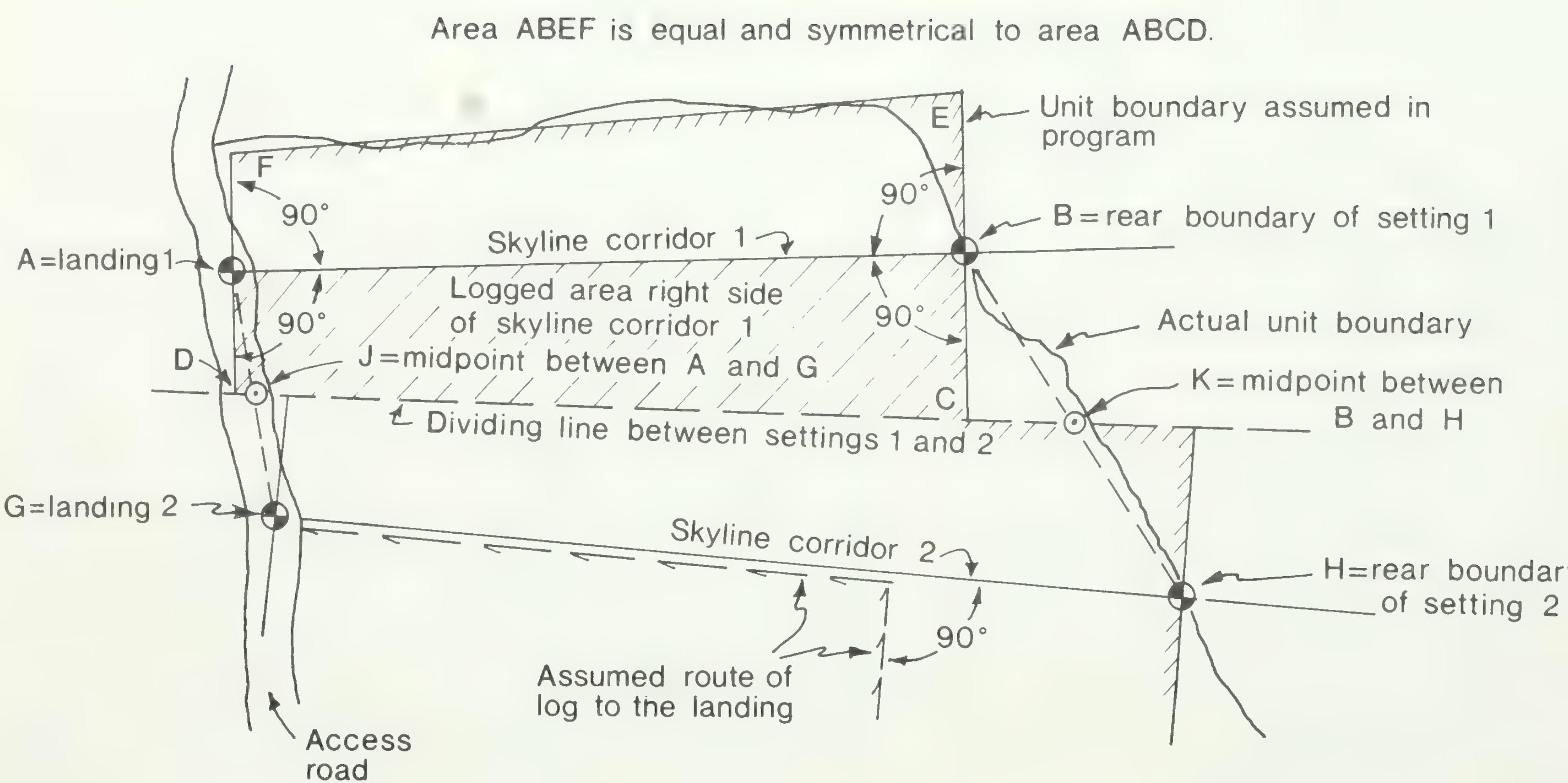


Figure 1.--Geometric assumptions of program 2.

dicular to the skyline exist, the lateral yarding may extend only in the downhill direction and all the way to the next corridor. Calculating a more accurate lateral yarding distance in these situations can be managed by analyzing the portions of the unit where transverse slopes prevail on a separate basis and *doubling* the lateral yarding distance output from the program. Some additional hand calculations are needed to arrive at the correct weighted averages for the setting and unit summaries.

The method described in this paper uses the algorithm depicted by figure 2.

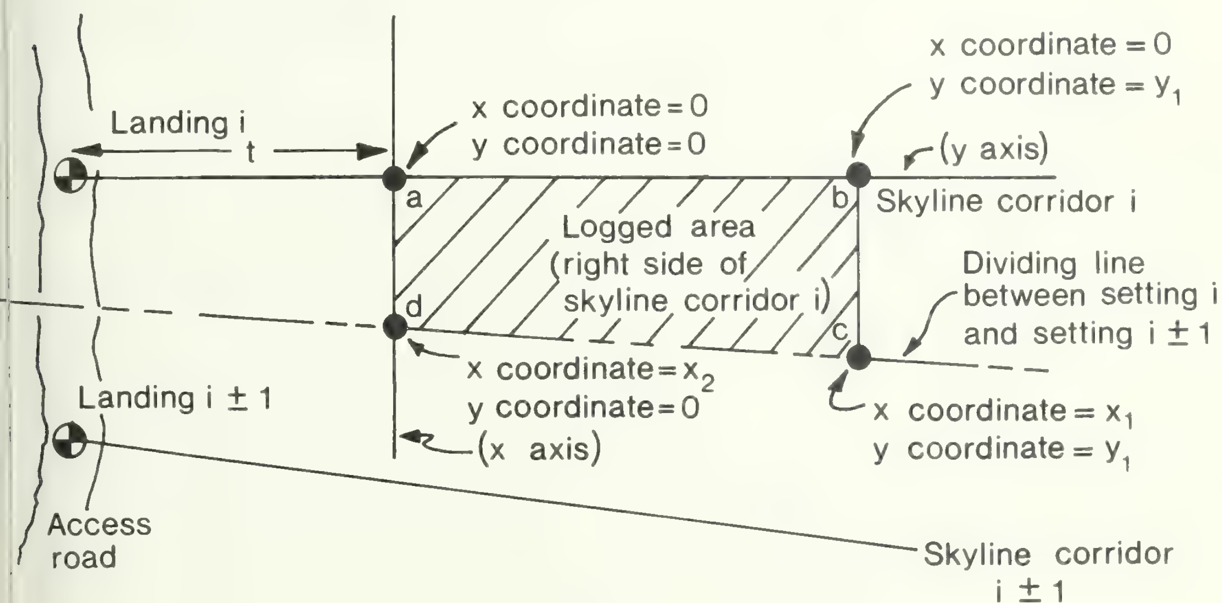


Figure 2.--Geometric basis of program 2.

For polygon abcd, lateral AYD is solved as follows:

$$A = y_1 \frac{(x_1 + x_2)}{2};$$

$$M_{lat} = y_1/6\ (x_1{}^2 + x_1x_2 + x_2{}^2);$$

and

$$AYD_{lat} = \frac{\Sigma M_{lat}}{\Sigma A}\ .$$

Longitudinal AYD is solved as follows:

$$M_{long} = y_1{}^2/6\ (2x_1 + x_2) + At;$$

and

$$AYD_{long} = \frac{\Sigma M_{long}}{\Sigma A}\ .$$

User's Guide

Detailed operating instructions and the program listings are given for computer systems programable in the ASCII BASIC language. They were developed on a Hewlett-Packard 9830A desk-top calculator/plotter/digitizer system but can be executed on equivalent hardware.[1]

The minimum Hewlett-Packard calculator system configurations needed to run these programs are:

1. Model 9830A calculator with 7,904 words of read/write memory.

2. Additional read-only memories; extended input/output and string variables.

3. Digitizer (9864A).

4. Thermal page printer (9866A).

OPERATING PROCEDURE FOR PROGRAM 1

The following procedures presume a knowledge of the Hewlett-Packard Model 9830A system procedures. Only supplemental instructions pertaining to this program will be detailed.

This program can be put on a magnetic tape cassette and executed as follows:

1. Press LOAD, 1, EXECUTE.

   This loads the program.

2. Secure unit map to digitizer surface.

   Map must contain the needed input data:

   --*proposed cutting unit(s) outlined;*
   --*landing location(s) marked.*

3. Press RUN, EXECUTE.

   --*At this point the program assists the user by requesting input through visual prompters in the display.*
   --*Continue through entries in table 1 which relate the keyboard and digitizer inputs to the visual prompters on the computer display.*

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader and does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product to the exclusion of others which may be suitable.

Table 1--Input explanation for average yarding distance, program 1

Visual prompter on display	Sample keyboard response	Explanation
NEED INSTRUCTIONS (YES/NO)	YES	Prints operating instructions in response to "YES" input (fig. 3).
MAP SCALE (FEET/INCH)	400	Enters scale of map being used.
NUMBER OF SETTINGS	3	Enters the number of settings required to yard the unit.
AVERAGE PERCENT SLOPE	45	Enters the average ground slope of the setting; if the unit is to be yarded with skylines, enters the average skyline chord slope.
SETTING DESIGNATION	1	1. Sequentially enters the unit that will be digitized next. 2. When the last setting has been digitized, prints the final output.
DIGITIZE SETTING		DIGITIZER RESPONSE 1. Follow instructions printed and shown in figure 3. 2. See figure 4 for additional information on digitizing technique for complicated units.

Figure 3.--Operating instructions for AYD Program 1.

Figure 4.--Sample of acceptable cursor route for digitizing complex settings.

EXAMPLE DATA FOR PROGRAM 1

Figures 5 and 7 illustrate timber harvest units which have been digitized with the corresponding printed output from the programed calculator shown by figures 6 and 8. The average time to set up, digitize, and analyze each unit is about 1 minute.

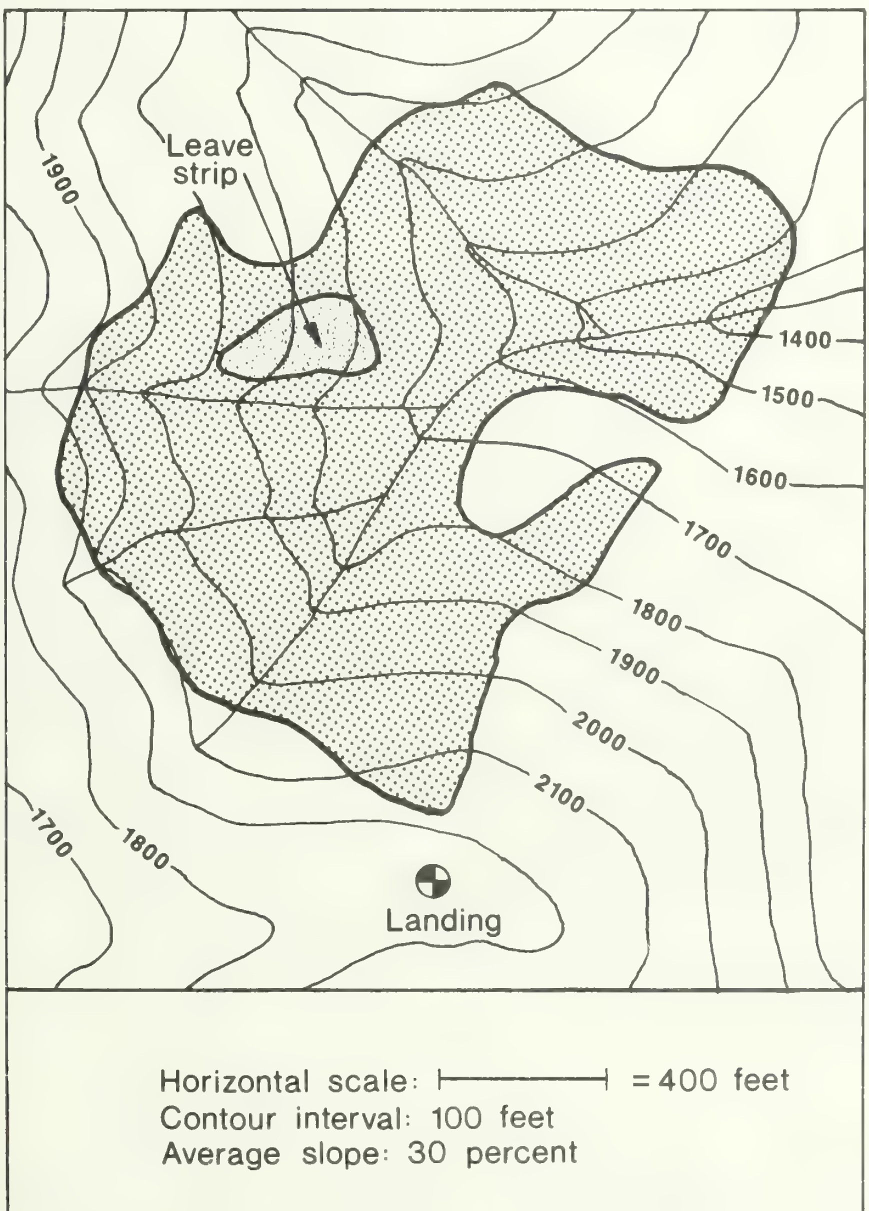
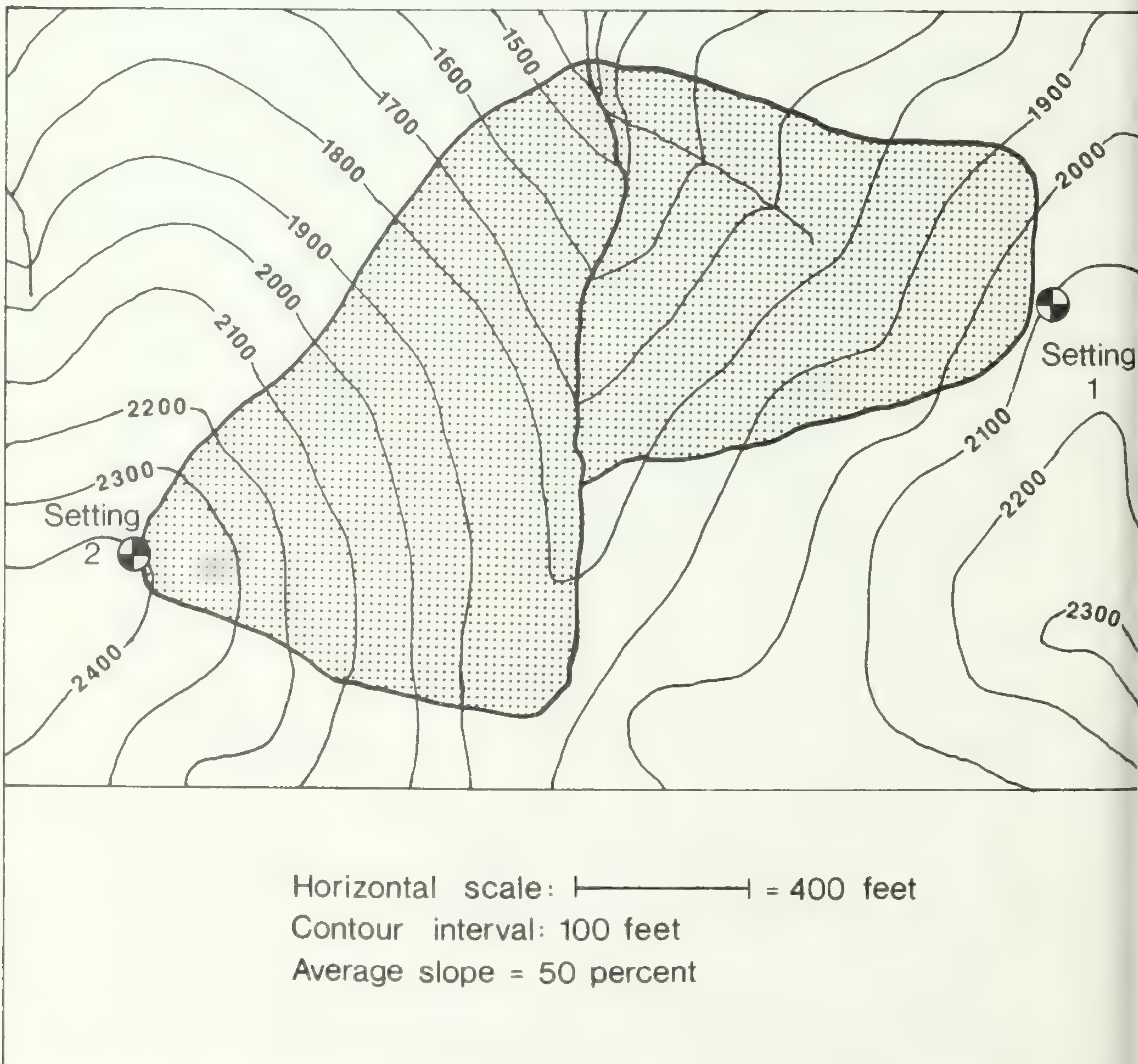


Figure 5.--Irregular-shaped cutting unit.

ACRES

Figure 6.--Printed output from example (fig. 5).

Figure 7.--Large unit yarded from two settings.



```
[illegible] 1 INCH = 400 FEET

[illegible]   [illegible]   AREA      [illegible]   [illegible]   [illegible]
              SLOPE         (ACRES)   [illegible]
              (%)                     DISTANCE
                                      (FT)

1             50            16.44     [illegible]   [illegible]   [illegible]
              [illegible]   21.49     [illegible]   [illegible]   [illegible]

[illegible] SETTINGS

        AREA= [illegible]
        AYD= [illegible]
        AYD= [illegible] FEET (WITH SLOPE CORRECTION)
```

Figure 8.--Printed output from example (fig. 7).

PERATING PROCEDURE FOR PROGRAM 2

This program can be stored on the magnetic tape cassette containing rogram 1 and executed as follows:

1. Press LOAD, 2, EXECUTE.

   This loads the program.

2. Secure unit map to digitizer surface.

   Map must contain the needed input data:

   --proposed cutting unit outlined;
   --landing location(s) marked;
   --rear boundary of the skyline corridors marked.

3. Press RUN, EXECUTE.

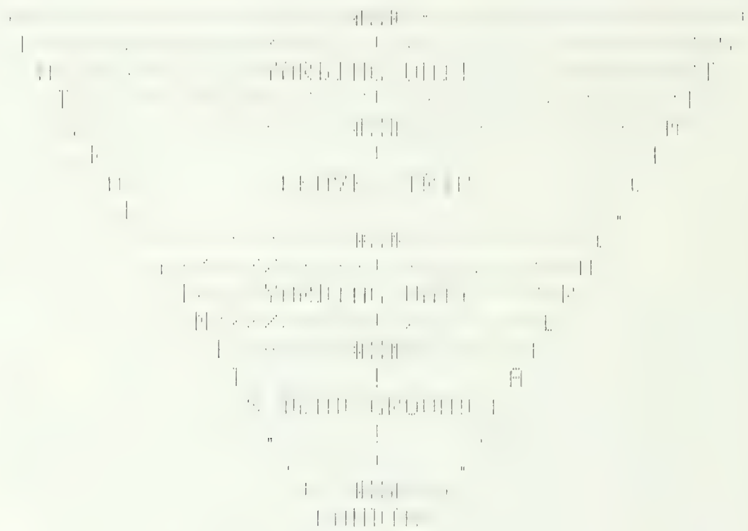
   --The program's title and the definition of unit types are printed (fig. 9).
   --Next, the program assists the user by requesting input through visual prompters in the display.
   --Continue through entries in table 2 which relate the keyboard and digitizer inputs to the visual prompters on the computer display.

XAMPLE DATA FOR PROGRAM 2

Figures 10 and 12 illustrate timber harvest units which have been gitized with the corresponding printed output from the programed lculator shown by figures 11 and 13. The average time to set up, gitize, and analyze each unit is about 4 minutes.

[illegible]

UNIT CODES:
1 = NO LEAVE STRIP OR DEAD GROUND
2 = WITH DEAD GROUND
3 = WITH LEAVE STRIP
4 = WITH DEAD GROUND AND LEAVE STRIP



[illegible]
[illegible]

OPERATING INSTRUCTIONS:
1.[illegible]
2.[illegible]
3.DIGITIZE EACH SETTING (PRESS S AT [illegible])
IN THE FOLLOWING SEQUENCE:
#1# LANDING
#2# DEAD GROUND BOUNDARY (IF ANY)
#3# NEAR BOUNDARY OF LEAVE STRIP (IF ANY)
#4# FAR BOUNDARY OF LEAVE STRIP (IF ANY)
#5# FAR BOUNDARY OF YARDING UNIT.
DIGITIZE THIS LAST POINT [illegible] SETTING
CONTAINS BOTH DEAD GROUND AND A LEAVE STRIP;
IN THAT CASE DIGITIZE THIS POINT JUST ONCE.
4.DON'T DIGITIZE TOO FAST. WAIT FOR THE AUDIBLE "BEEP" AND
[illegible] BEFORE DIGITIZING SUBSEQUENT POINTS.
5.[illegible] FOR UNIT [illegible] OF A GROUP OF ADJACENT SETTINGS:
[illegible] FOR THE SETTING FOLLOWING THE FINAL
SETTING.
6.UNIT [illegible] MUST BE PERFORMED [illegible] THE AREA BETWEEN
SETTINGS IS NOT TO BE YARDED.
7.SETTINGS MUST BE DIGITIZED IN A SEQUENTIAL ORDER,
STARTING AT THE LEFT (OR RIGHT) BOUNDARY AND PROCEEDING
TO THE OPPOSITE BOUNDARY.

Figure 9.--Operating instructions for AYD program 2.

Table 2--Input explanation for average yarding distance, program 2

Visual prompter on display	Sample keyboard response	Explanation
NEED INSTRUCTIONS (YES/NO)	YES	Prints operating instructions in response to "YES" input (fig. 9).
MAP SCALE (FEET/INCH)	400	Enters scale of map being used.
SKYLINE CHORD SLOPE %; SETTING *i*	30	1. Uses this value to calculate the relationship between horizontal and actual yarding distance.
	1	2. After the last setting in the unit is digitized, enter a value of 1 to signal for printed unit summary.
DIGITIZE LANDING *i*		DIGITIZER RESPONSE (fig. 9).
NEXT POINT, SETTING *i*		DIGITIZER RESPONSE (fig. 9).

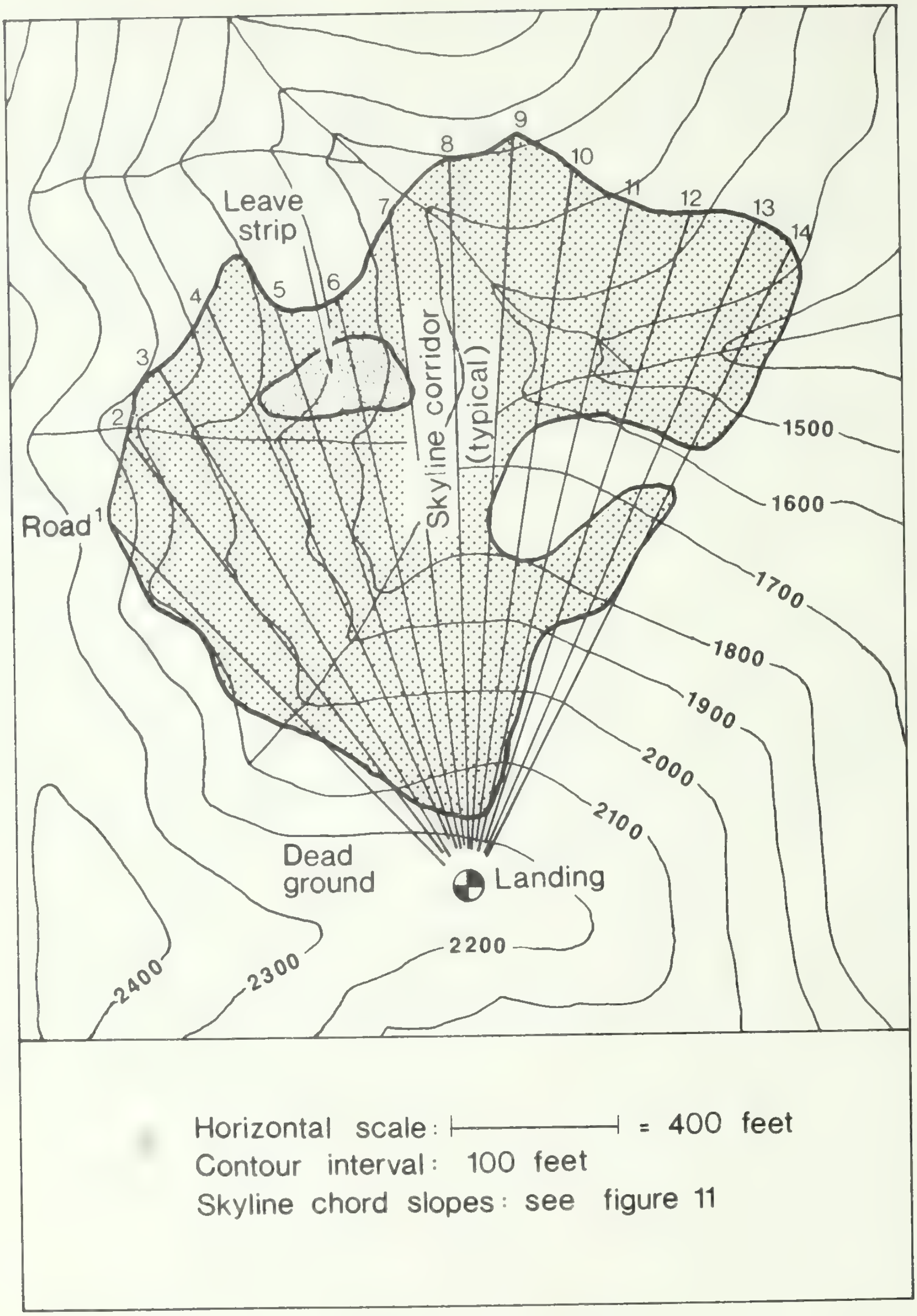


Figure 10.--Irregular unit yarded in fan-shaped pattern.

AVERAGE YARDING DISTANCE (AYD) FOR LATERAL AND LONGITUDINAL YARDING

UNIT TYPES:
1 NO LEAVE STRIP OR DEAD GROUND
2 WITH DEAD GROUND
3 WITH LEAVE STRIP
4 WITH DEAD GROUND AND LEAVE STRIP

[illegible] 400 FEET

[illegible]	[illegible]	AVERAGE SLOPE (%)	AREA (ACRES)	LAT. AYD (FT)	LONG. [illegible] (FT)	[illegible]	ADJ. LONG. [illegible] DIST. (FT)	[illegible] LAT. DIST. (FT)
1	2	4	1.3[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	13	2.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	2	9	2.79	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	2	16	2.91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4	20	2.[illegible]	24	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2	[illegible]	3.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	26	3.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	2.4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	2.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	40	2.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	1	43	2.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	4	46	1.4[illegible]	21	[illegible]	[illegible]	1915	[illegible]

[illegible] SETTINGS

[illegible] ACRES
LATERAL AYD= [illegible] FEET
LONGITUDINAL AYD= 1125 FEET (NO SLOPE CORRECTION)
LONGITUDINAL AYD= 1176 FEET (WITH SLOPE CORRECTION)
TOTAL AYD= [illegible]02 FEET (WITH SLOPE CORRECTION)
SLOPE CORRECTION = 50 FEET
(UNITS ARE AREA WEIGHTED MEANS)

Figure 11.-- Printed output from example (fig. 10).

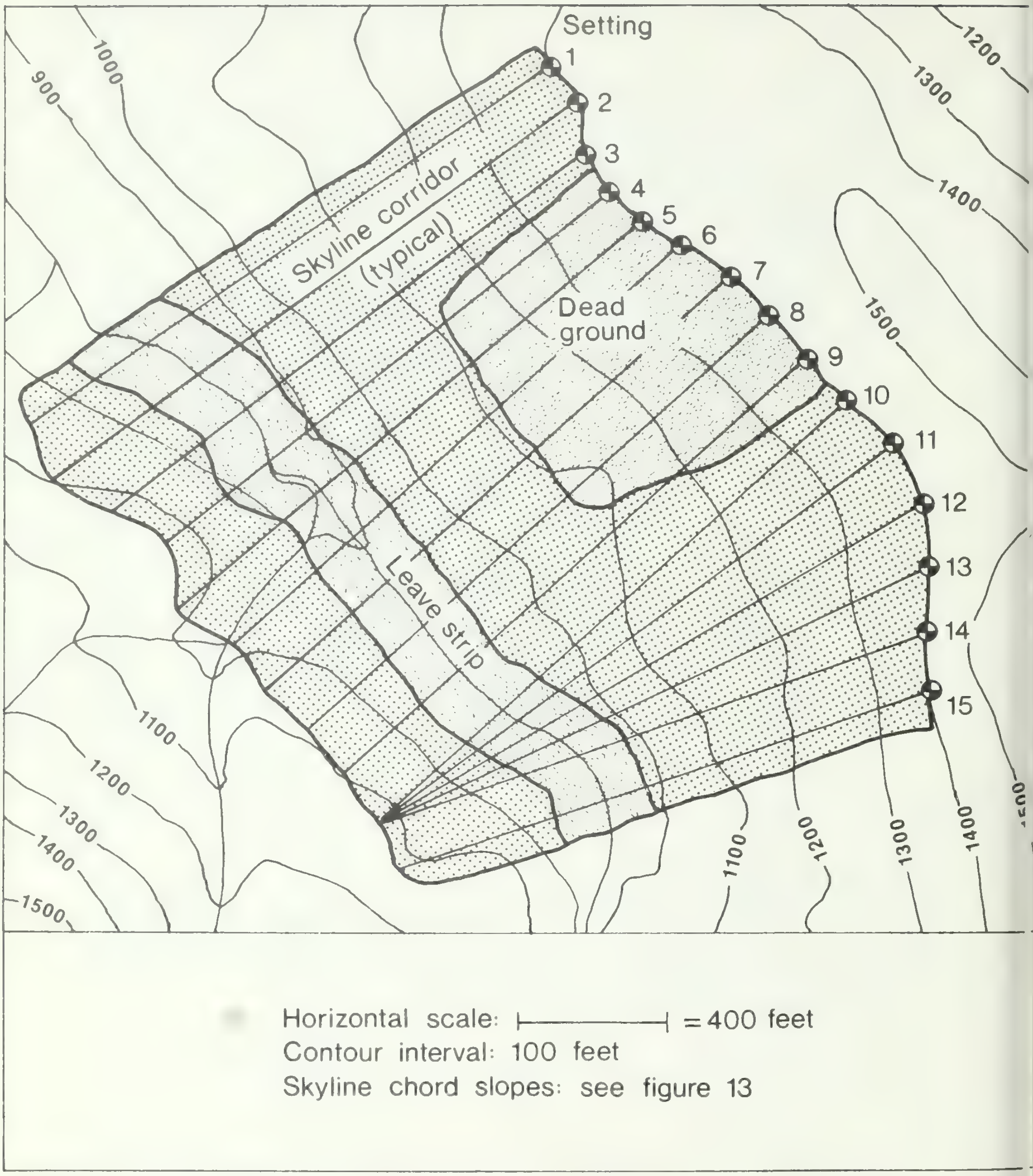


Figure 12.--Unit yarded with a combination of parallel and fan-shaped settings

[illegible]

[illegible]
1 = NO LEAVE STRIP OR DEAD GROUND
2 = WITH DEAD GROUND
3 = WITH LEAVE STRIP
4 = WITH DEAD GROUND AND LEAVE STRIP

[illegible] FEET

SETTING NO	TYPE	AVERAGE SLOPE (%)	AREA (ACRES)	LAT AYD (FT)	LONG [illegible] AYD (FT)	[illegible] AYD (FT)	MAX. LONG. SLOPE DIST. (FT)	MAX. LAT. DIST. (FT)
1	3	30	4.19	33	[illegible]	[illegible]	[illegible]	[illegible]
2	3	26	4.68	35	[illegible]	[illegible]	[illegible]	[illegible]
3	3	27	4.32	35	[illegible]	[illegible]	[illegible]	84
4	4	29	2.27	36	1046	[illegible]	[illegible]	[illegible]
5	4	27	2.67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	4	29	2.43	38	1176	[illegible]	[illegible]	[illegible]
7	4	24	2.47	38	[illegible]	1250	[illegible]	[illegible]
8	4	22	2.39	38	[illegible]	[illegible]	[illegible]	[illegible]
9	4	21	3.35	39	1058	[illegible]	[illegible]	[illegible]
10	[illegible]	20	4.15	36	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	19	3.16	30	534	[illegible]	[illegible]	[illegible]
12	3	20	2.98	30	514	[illegible]	[illegible]	[illegible]
13	3	20	2.70	[illegible]	[illegible]	515	[illegible]	[illegible]
14	3	21	3.46	35	[illegible]	[illegible]	[illegible]	[illegible]
15	3	22	4.30	37	[illegible]	[illegible]	[illegible]	[illegible]

TOTAL FOR 15 SETTINGS

AREA= 49.54 ACRES
LATERAL AYD= 35 FEET
LONGITUDINAL AYD= 812 FEET (NO SLOPE CORRECTION)
LONGITUDINAL AYD= 837 FEET (WITH SLOPE CORRECTION)
TOTAL AYD= 872 FEET (WITH SLOPE CORRECTION)
SLOPE CORRECTION = 24 FEET
(AYD'S ARE AREA WEIGHTED MEANS)

Figure 13.--Printed output from example (fig. 12).

Literature Cited

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1964. Average skidding distance for theoretical analysis of logging costs. Res. Bull. 789, 6 p., illus. Purdue Univ. Agric. Exp. Stn., Lafayette, Ind.

Appendix

Program Listings

PROGRAM 1

```
[illegible]
[illegible]
[illegible] SHAPED HARVEST S[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] DISPLAY STATEMENT
[illegible] ORIGIN [illegible] DIGITIZER CURSOR)"
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] FOR ALL SE[illegible]
[illegible]
[illegible]
210 DISP "MAP SCALE (FEET/INCH)";
[illegible]
[illegible]
[illegible]
[illegible] INPU[illegible]
[illegible]
[illegible]
[illegible] PRIN[illegible]
[illegible]
[illegible] LOPE [illegible]
[illegible] PRINT "        AYD"
[illegible]
[illegible] PRINT TAB39" (FT)"
[illegible]
[illegible]
360 NEXT J
[illegible]
[illegible]
[illegible]
[illegible]
410 INPUT A$
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
```

```
10 [illegible]
20 REM***(TEST:HAS CURSOR LEFT LANDING ?
30 IF R? 0.05 THEN 550
40 [illegible]
50 [illegible]
60 REM****TEST:MAX HORIZONTAL DISTANCE
70 IF R2 [illegible] THEN 590
80 [illegible]
90 [illegible]
00 [illegible]
10 [illegible]
20 [illegible]
30 [illegible]
40 [illegible]
50 [illegible]
60 [illegible]
70 [illegible]
80 [illegible]
90 [illegible]
00 [illegible]
10 [illegible]
20 [illegible]
30 [illegible]
40 [illegible]
50 [illegible]
60 [illegible]
70 [illegible]
80 [illegible]
90 NEXT I
00 [illegible]
10 [illegible]
20 [illegible]
30 [illegible]
40 [illegible]
50 [illegible]
60 [illegible]
70 [illegible]
80 [illegible]
90 [illegible]
00 [illegible]
10 [illegible]
20 [illegible]
30 [illegible]
40 [illegible]
50 [illegible]
60 [illegible]
70 [illegible]
80 [illegible]
90 [illegible]
1000 [illegible]
1010 [illegible]
1020 [illegible]
1030 [illegible]
1040 [illegible]
```

PROGRAM 2

```
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
60 PRINT "UNIT TYPES:"
[illegible]
[illegible] PRINT TAB10"2--DEAD GROUND"
[illegible]
[illegible]
[illegible]
[illegible]
130 DISP "NEED INSTRUCTIONS (YES/NO)";
140 INPUT A$
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
300 P=P+1
[illegible]
320 P=P+1
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
390 IF Z9<0.04 THEN 460
400 P=P+1
[illegible]
420 P=P+1
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
```

```
[N,13]=2
O TO 560
[N,13]=3
O TO 560
[N,13]=4
[N,12]=51
[N,1]=N
O TO 210
EM***REORGANIZE DIGITIZED POINTS
=0
=N+1
F A[N,1]=0 THEN 830
F A[N,13]=1 THEN 670
F A[N,13]=2 THEN 710
F A[N,13]=3 THEN 750
F A[N,13]=4 THEN 610
[N,10]=A[N,4]
[N,11]=A[N,5]
[N,5]=A[N,4]=0
O TO 610
[N,10]=A[N,6]
[N,11]=A[N,7]
[N,6]=A[N,7]=0
O TO 610
N,10]=A[N,8]
N,11]=A[N,9]
N,8]=A[N,6]
N,9]=A[N,7]
N,6]=A[N,4]
N,7]=A[N,5]
N,4]=A[N,5]=0
 TO 610
M****CALCULATE YARDING DISTANCES
INT "MAP SCALE; 1 INCH="S" FEET"
INT
INT
INT "SETTING  TYPE  AVERAGE     AREA     LAT.     LONG.   ";
INT " COMB.    MAX.     MAX."
INT "  OR               SLOPE      (ACRES)   AYD      SLOPE     AYD    LONG."
INT "    LAT."
INT " ROAD"TAB17"(%)"TAB36"(FT)"TAB44"AYD"TAB52"(FT)"TAB60"SLOPE   DIST."
INT "   NO."TAB44"(FT)"TAB60"DIST.    (FT)"
INT TAB60"(FT)"
INT "  ---       ---       ---          ---       ---       ---       ---     ---";
INT "     ----"
G
L3=L4=H5=H2=C3=C4=C7=0
=N+1
 A[N,2]#A[N,10] THEN 1010
A[N,10]=A[N,10]+0.001
```

```
1010 [illegible]
1020 [illegible]
1030 IF [illegible] THEN 1[illegible]
1040 IF [illegible] THEN 1[illegible]
1050 IF [illegible] THEN 2170
1060 IF [illegible] THEN 1150
1070 [illegible]
1080 GOSUB [illegible]
1090 GOSUB [illegible]
1100 IF I4 [illegible] I3 THEN 1130
1110 [illegible]
1120 [illegible]
1130 [illegible]
1140 IF [illegible] THEN 1220
1150 [illegible]
1160 GOSUB [illegible]
1170 GOSUB [illegible]
1180 IF I4 [illegible] I3 THEN 1210
1190 [illegible]
1200 [illegible]
1210 I9=I4
1220 IF [illegible] THEN 1300
1230 [illegible]
1240 [illegible]
1250 H2=H2*2
1260 IF [illegible] THEN [illegible]
1270 [illegible]
1280 [illegible]
1290 [illegible]
1300 C1=L3*S/H2
1310 C2=L4*S/H2
1320 [illegible]
1330 GOSUB [illegible]
1340 [illegible]
1350 [illegible]
1360 IF [illegible] THEN 1450
1370 [illegible]
1380 GOSUB [illegible]
1390 GOSUB [illegible]
1400 IF I4 [illegible] I5 THEN 1430
1410 [illegible]
1420 [illegible]
1430 [illegible]
1440 IF [illegible] THEN [illegible]
1450 [illegible]
1460 GOSUB [illegible]
1470 GOSUB [illegible]
1480 IF I4 [illegible] I5 THEN 1510
1490 [illegible]
1500 [illegible]
```

```
510 [illegible]
520 IF A(I4+1,L1)<>A(I,N1) THEN [illegible]
530 [illegible]
540 L1=L1+2
550 H2=H2*2
560 IF N>L THEN 1590
570 I8=I9
580 GO TO 1600
590 [illegible]
600 [illegible]
610 [illegible]
620 [illegible]
630 GOSUB [illegible]
640 GO TO [illegible]
650 C5=[illegible]H5
660 C6=C4*H5
670 C8=C7*H5
680 PRINT
690 PRINT
700 PRINT "TOTAL FOR "N" SETTINGS:"
710 PRINT
720 FIXED 2
730 PRINT TAB10"AREA="H5"ACRES."
740 FIXED 0
750 PRINT TAB10"LATERAL [illegible] FEET
760 PRINT TAB10"LONGITUDINAL [illegible] SLOPE [illegible]
770 PRINT TAB10"LONGITUDINAL [illegible] CORRECTION
780 C9=C5+C8
790 PRINT TAB10"TOTAL [illegible]
800 PRINT TAB10"SLOPE CORRECTION [illegible]
810 PRINT TAB12"(HYD'S ARE [illegible])"
820 PRINT
830 PRINT
840 GO TO [illegible]
850 REM***CASE 3
860 IF A(I1+1,L)=0 THEN 1950
870 I=I1+1
880 GOSUB 2160
890 GOSUB 3050
900 IF I4 [illegible] I3 THEN 1930
910 I8=I3
920 GO TO 1940
930 I8=I4
940 IF N=1 THEN 2020
950 I=I1
960 GOSUB 2160
970 GOSUB 3050
980 IF I4 [illegible] I3 THEN [illegible]
990 I9=I3
000 GO TO [illegible]
```

```
[illegible]
[illegible]
2030 L3=[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
2150 REM****CASE 4
[illegible]
[illegible]
[illegible]
[illegible] GOSUB [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] I9=I4
[illegible]
[illegible]
[illegible]
[illegible] I2=H2*2
[illegible]
[illegible] I8=[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
2430 [illegible]
[illegible]
[illegible] STOP
[illegible]
[illegible]
[illegible]
2490 [illegible]
[illegible]
```

```
510 D6=SQR((A[N,2]-R1)↑2+(A[N,3]-Y1)↑2)
520 D7=SQR((A[N,2]-R5)↑2+(A[N,3]-Y5)↑2)
530 IF A[N,2]#R1 THEN 2550
540 R1=R1+0.001
550 A1=ATN((A[N,3]-Y1)/(A[N,2]-R1))
560 IF A[N,2]#R5 THEN 2580
570 R5=R5+0.001
580 A5=ATN((A[N,3]-Y5)/(A[N,2]-R5))
590 Z1=90-ABS(A-A1)
600 Z5=90-ABS(A-A5)
610 R6=D6*COS(Z1)
620 Y6=D6*SIN(Z1)
630 R7=D7*COS(Z5)
640 Y7=D7*SIN(Z5)
650 I2=(R7-R6)/(Y7-Y6)
660 I3=R6-(Y6*(R7-R6)/(Y7-Y6))
670 I4=D*I2+I3
680 RETURN
690 REM*****CASE 1 SUBROUTINE
700 H1=ABS(D*(I3+I4)/2)
710 L1=ABS((D/6)*(I3↑2+(I3*I4)+I4↑2))
720 L2=ABS(D↑2*(2*I4+I3)/6)
730 L3=L3+L1
740 L4=L4+L2
750 H2=H2+H1
760 RETURN
770 REM*******PRINTING SUB ROUTINE
780 F2=C2*SQR((A[N,12]/100)↑2+1)
790 F3=C1+F2
800 F4=D*S*SQR((A[N,12]/100)↑2+1)
810 IF I8 >= I9 THEN 2840
820 G7=I9
830 GO TO 2850
840 G7=I8
850 G8=G7*S
860 FORMAT F4.0,F8.0,F8.0,F11.2,F8.0,F9.[illegible]
870 WRITE (15,2860)N,A[N,13],A[N,12],H3,[illegible]
880 C3=C3+(F1*H3)
890 C4=C4+(F2*H3)
900 C7=C7+(C2*H3)
910 H5=H5+H3
920 L3=L4=H2=0
930 IF A[N+1,1]=0 THEN 1650
940 RETURN
950 REM*****CASE 2 SUB ROUTINE
960 D3=SQR((A[N,2]-A[N,4])↑2+(A[N,3]-A[N,5])↑2)
970 I5=D3*I2+I3
980 H1=ABS((D-D3)*(I4+I5)/2)
990 L1=ABS((D-D3)/6*(I5↑2+(I4*I5)+I4↑2))
000 L2=ABS((D-D3)↑2*(2*I4+I5)/6)
```

```
[illegible]
[illegible]
[illegible]
[illegible] RETURN
[illegible]
[illegible]
[illegible] D1= [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] AB [illegible]
[illegible]
[illegible] AB [illegible]
[illegible] L1 [illegible]
[illegible] L2 [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] D1 [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] AB [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
3420 [illegible]URN
3430 [illegible]
3440 [illegible]
3450 PR[illegible]
[illegible] PRINT TAB21"L[illegible]
3470 [illegible]
3480 [illegible]
[illegible]
[illegible]
[illegible]
[illegible] PR[illegible]
```

```
PRINT [illegible]
PRINT TAB29"[illegible]"
PRINT TAB30"I [illegible] YARDING UNIT [illegible]"
PRINT TAB31"N [illegible]"
PRINT TAB32"I--------#X#--------T"
PRINT TAB33"T          !          N"
PRINT TAB34"S DEAD GROUND L"
PRINT TAB35".        !        ."
PRINT TAB36".       !       ."
PRINT TAB37"[illegible]#X#[illegible]"
PRINT TAB38"LANDING"
PRINT
PRINT
PRINT ""LEAVE STRIP"-UNLOGGED AREA IN THE UNIT"
PRINT "*DEAD GROUND"-UNLOGGED AREA BETWEEN LANDING AND UNIT"
PRINT
PRINT "OPERATING INSTRUCTIONS:"
PRINT TAB5"1.INPUT DATA AS REQUIRED BY PROGRAM."
PRINT TAB5"2.ESTABLISH AN ORIGIN TO THE CURSOR."
PRINT TAB5"3.DIGITIZE EACH SETTING (PRESS S AT EACH #X# LOCATION)"
PRINT TAB8"IN THE FOLLOWING SEQUENCE:"
PRINT TAB10"#X# LANDING$"
PRINT TAB10"#X# DEAD GROUND BOUNDARY (IF ANY)$"
PRINT TAB10"#X# NEAR BOUNDARY OF LEAVE STRIP (IF ANY)$"
PRINT TAB10"#X# FAR BOUNDARY OF LEAVE STRIP (IF ANY)$"
PRINT TAB10"#X# REAR BOUNDARY OF YARDING UNIT."
PRINT TAB13"DIGITIZE THIS LAST POINT ONCE UNLESS SETTING"
PRINT TAB13"CONTAINS BOTH DEAD GROUND AND A LEAVE STRIP$"
PRINT TAB13"IN THAT CASE DIGITIZE THIS POINT JUST ONCE."
PRINT TAB5"4.DON'T DIGITIZE TOO FAST. WAIT FOR THE AUDIBLE "BEEP" AND"
PRINT TAB8"DISPLAY BEFORE DIGITIZING SUBSEQUENT POINTS."
PRINT TAB5"5.TO SIGNAL FOR UNIT SUMMATION OF A GROUP OF ADJACENT SETTINGS,"
PRINT TAB8"ENTER A 1 IN CHORD SLOT FOR THE SETTING FOLLOWING THE FINAL"
PRINT TAB8"SETTING."
PRINT TAB5"6.UNIT SUMMATION MUST BE PERFORMED WHENEVER THE AREA BETWEEN"
PRINT TAB8"SETTINGS IS NOT TO BE YARDED."
PRINT TAB5"7.THE SETTINGS MUST BE DIGITIZED IN A SEQUENTIAL ORDER,"
PRINT TAB8"BEGINNING AT THE LEFT (OR RIGHT) BOUNDARY AND PROCEEDING"
PRINT TAB8"TO THE OPPOSITE BOUNDARY."
PRINT
PRINT
GO TO [illegible]
```

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2. Developing and evaluating alternative methods and levels of resource management.

3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

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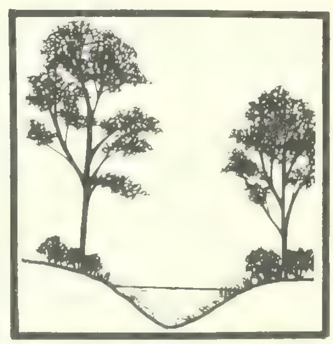
GENERAL TECHNICAL REPORT PNW-80

WILDLIFE HABITATS IN MANAGED RANGELANDS-- THE GREAT BASIN OF SOUTHEASTERN OREGON

RIPARIAN ZONES

JACK WARD THOMAS
CHRIS MASER
JON E. RODIEK



PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

ABSTRACT

Riparian zones are the most critical wildlife habitats in managed rangelands. More wildlife species depend entirely on or spend disproportionately more time in this habitat than any other. The zone is also disproportionately important for grazing, recreation, timber production, fisheries production, road location and water quality and quantity. The importance to wildlife is examined and guidance given for management.
KEYWORDS: Riparian habitat, wildlife habitat.

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This publication is part of the series **Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon**. The purpose of the series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands in order that the manager may make fully informed decisions.

The information in this series is specific to the Great Basin of Southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area but in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive whole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.

Introduction

Riparian zones can be identified by the presence of vegetation that requires free or unbound water or conditions that are more moist than normal (fig. 1) (Franklin and Dyrness 1973, Minore and Smith 1971). Riparian zones can vary considerably in size and vegetative complex because of the many combinations that can be created between water sources (fig. 2) and physical characteristics of a site. Such characteristics include gradient, aspect, topography, soil, type of stream bottom, water quality, elevation, and plant community (Odum 1971). All riparian zones within managed rangelands of the western United States, however, have the following in common: (1) they create well-defined habitat zones within the much drier surrounding areas; (2) they make up a minor proportion of the overall area; (3) they are generally more productive in terms of biomass—plant and animal—than the remainder of the area; and (4) they are a critical source of diversity within rangelands (fig. 3). Carothers (1977), Carothers and Johnson (1975), and Curtis and Ripley (1975) have prepared summary papers on the subject of riparian habitats as associated with both range and forest areas.

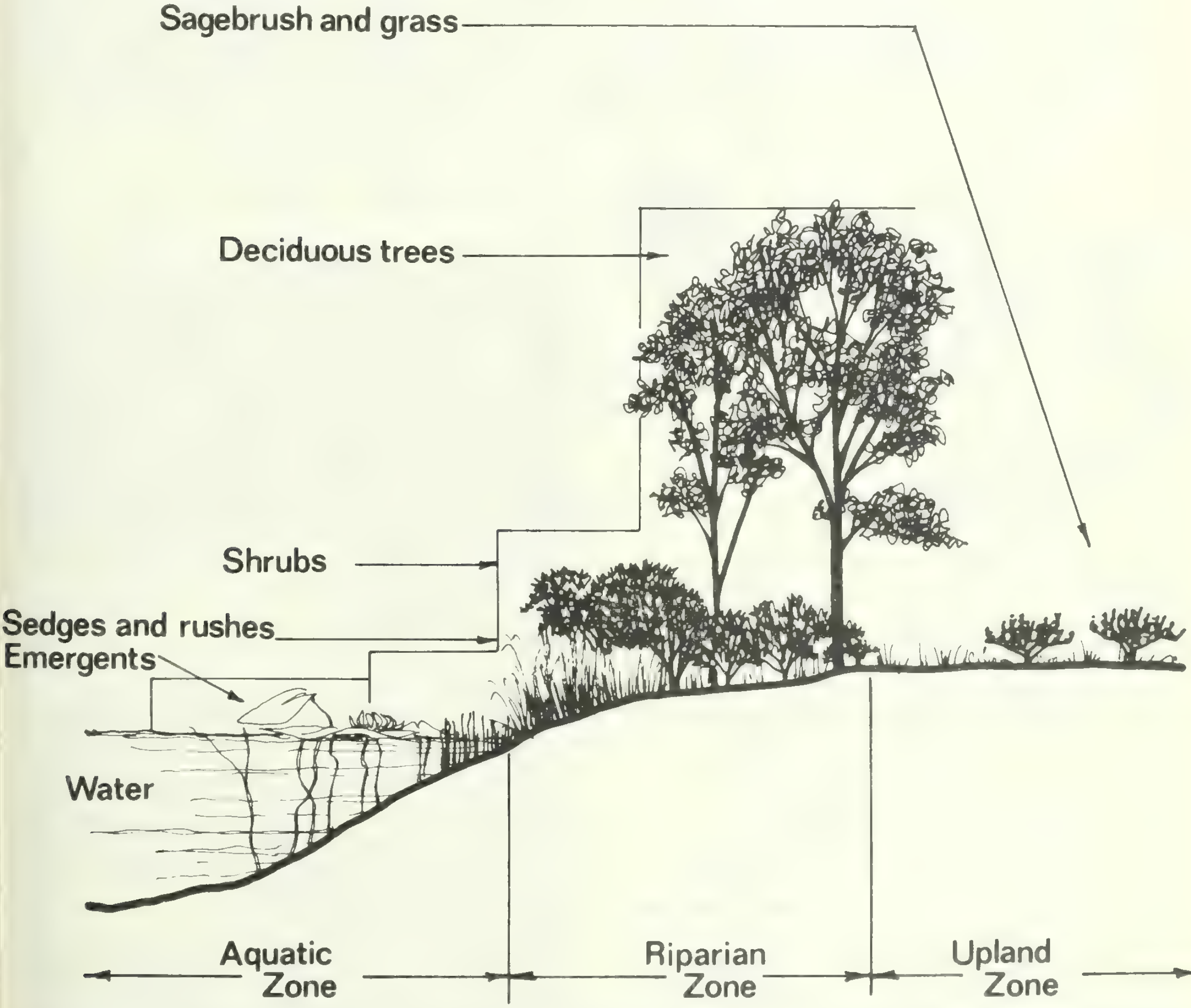


Figure 1.—Riparian zones are identified by the presence of vegetation that requires large amounts of free or unbound water.

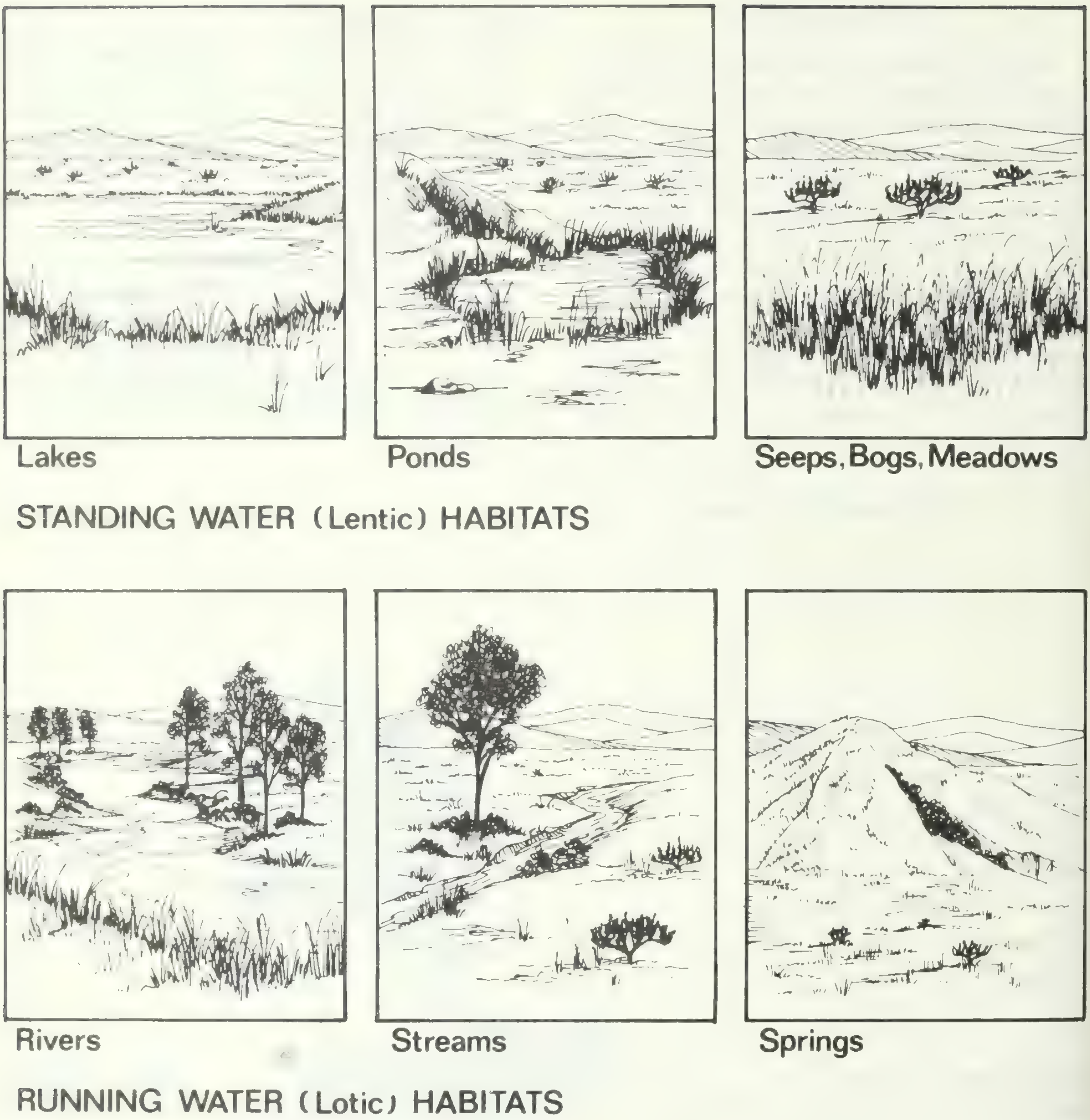


Figure 2.—The type of water source influences riparian vegetation (Odum 1971, p. 295).

IMPORTANCE OF RIPARIAN ZONES

Wildlife use riparian zones disproportionately more than any other type of habitat (Beidleman 1948 and 1954, Bottorff 1974, Dumas 1950, Gains 1977, Hinschberger 1978, Hubbard 1977, Kelley et al. 1975, Kirby 1975, and Wooding 1973). For example, of the 363 terrestrial species known to occur in the Great Basin of Southeastern Oregon, 288 are either directly dependent on riparian zones or utilize them more than other habitats (fig. 4). Many aquatic and semi-aquatic species are found nowhere else. Among such species are waterfowl and mammals, such as otter (*Lutra canadensis*), beaver (*Castor canadensis*), and muskrats (*Ondatra zibethicus*). Vertebrates that either reproduce or feed in water are totally dependent on riparian and adjacent

Figure 3.—Riparian zones are a critical source of diversity on western managed rangelands. Note the beaver (*Castor canadensis*) lodge in the upper right of the picture. (Robert R. Kindschy photograph).

aquatic zones. Of course, the water in these zones is the habitat for aquatic life forms—from invertebrates to fish, reptiles, amphibians, birds, and mammals. In short, riparian zones are the most critical wildlife habitats in managed rangelands.

Riparian zones in managed rangelands are also disproportionately important for other uses (fig. 5). Stream margins frequently contain highly productive forage sites. Cattle use the vegetation in riparian areas more heavily than that in other areas (Ames 1977, Kennedy 1977) because they concentrate in riparian areas to drink. The relative gentle topography, particularly in areas of otherwise rugged topography, makes riparian zones attractive for road locations. Streams, rivers, and their banks are also handy sources of rock and gravel for building roads. Mining has and does have direct and indirect impacts on riparian zones (Hill 1974) (fig. 6). Recreationists concen-

Figure 4.—Wildlife uses riparian zones disproportionately more than any other habitat type. (Robert R. Kindschy photograph).

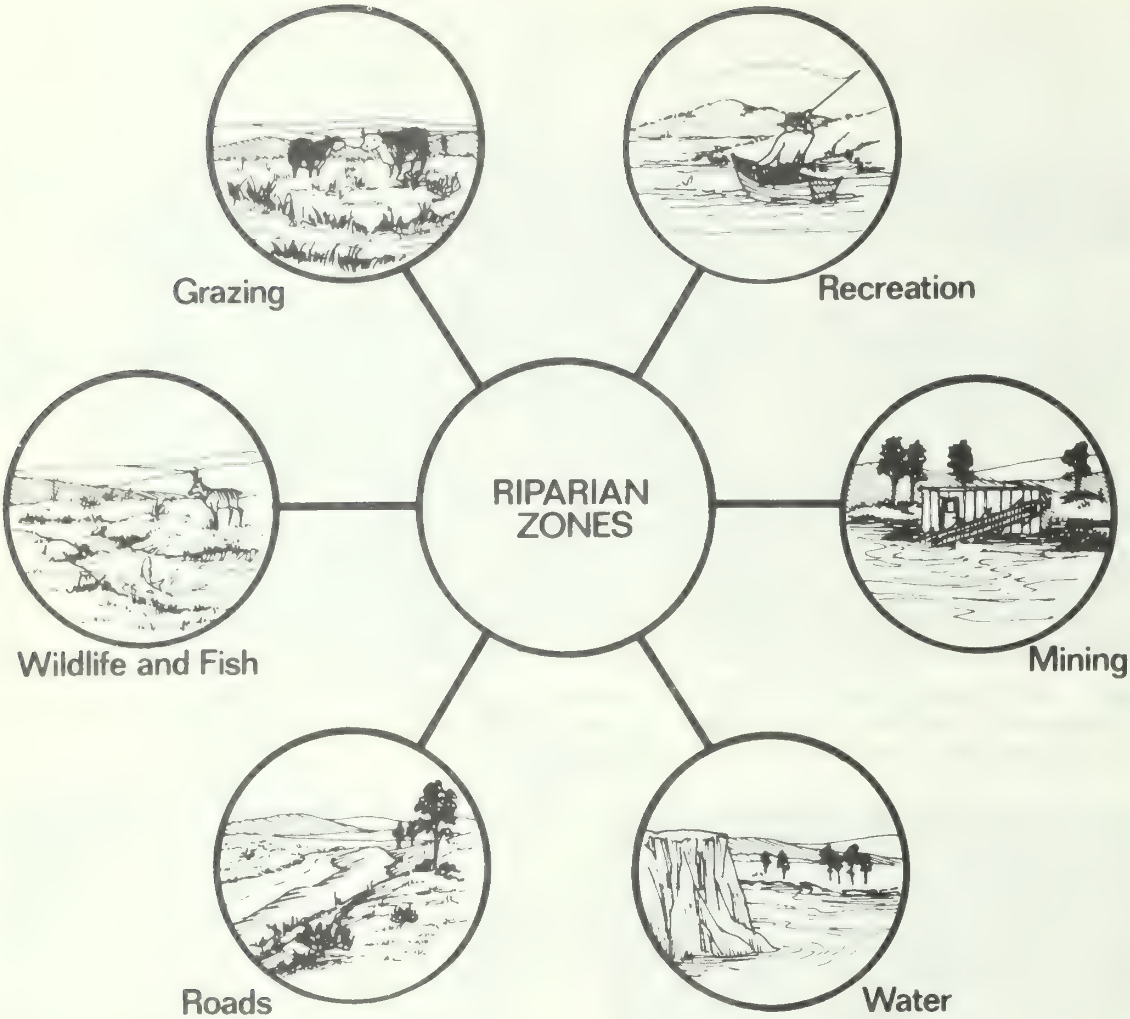


Figure 5.—Riparian zones are disproportionately important to many uses which makes them the most critical zones for multiple-use planning.

trate their use in such areas (Nash 1977). In addition, scenic values are often high. The water in such zones, particularly on dry western ranges, is critical to man's use, and rangelands are second only to cultivated lands as a source of water quality problems (Satterlund 1975). As a result, riparian zones are the most critical zones for multiple-use planning (Countess et al. 1977, Fox 1977, Lewis and Marsh 1977, Likens and Bormann 1974, Tuinstra 1967).

There are many reasons why riparian zones are so important to wildlife. Not all of these can be attributed to every riparian zone. Each combination of water source, site attributes, and management objectives must be considered separately by range managers. Some of these reasons are discussed below:

1. The presence of water lends importance to the zone. Wildlife habitat is composed of food, cover, and water. All riparian zones offer water, one of the critical habitat components, and some offer all three.

2. The greater availability of water to plants, frequently in combination with deeper soils, increases plant biomass production and provides a suitable site for plants that are limited elsewhere by inadequate water

Figure 6.—Mining activity has been frequently located in or adjacent to riparian zones causing severe disturbance. (Robert R. Kindschy photograph).

(Minore 1970, Minore and Smith 1971). In combination, these factors frequently lead to increased diversity of plant species and structural diversity in the community. Much of the diversity in species composition is accounted for by the presence of plants particularly adapted to wet or moist conditions, particularly those provided by surface as opposed to ground water (Campbell and Green 1968, Horton 1972, Maximov 1931). In the management sense, this means that riparian zones generally have a high rate of recovery or successional advancement of the vegetation when afforded proper conditions by protection or appropriate management.

3. The dramatic contrasts of the plant complex of the riparian zone with the general surrounding upland range vegetation adds to the structural diversity of the area (Jain 1976). For example, open wet meadows or groves of deciduous trees around seeps provide edges with stark contrast when they, in turn, are surrounded by relatively drier grasslands or shrublands. Moreover, those riparian zones dominated by deciduous vegetation provide one type of habitat during the summer when in full-leaf and another type of habitat during the winter following leaf-fall (Anderson and Ohmart 1977).

4. The shape of many riparian zones, particularly the linear nature of streams, maximizes the development of edge which is so productive of wildife (Bottorff 1974, Patton 1975). In those cases where streams flow through canyons, the canyon walls combine with the riparian zone to provide a unique habitat complex (fig. 7).

5. Riparian zones in rangelands frequently produce more edges within a small area than would be expected elsewhere (fig. 8). In addition, there are many vegetative strata exposed in stair-step fashion (fig. 8). This stair stepping of vegetation of contrasting form (deciduous vs. coniferous; shrubs vs. trees) provides diverse nesting and feeding opportunities for wildlife—especially birds and bats. The association of particular birds with distinct layers of vegetation has been repeatedly demonstrated (Dambach 1944, Lack 1933, MacArthur et al. 1962, Preston and Norris 1947, Thomas et al. 1977). In addition, birds have been shown to select between coniferous and deciduous vegetative volumes in distinct strata (DeGraaf 1976 and Thomas 1973).

Figure 7.—Where streams run through steep canyons, the cliff faces and the riparian zones combine to form a unique habitat unit. (Bureau of Land Management photograph).

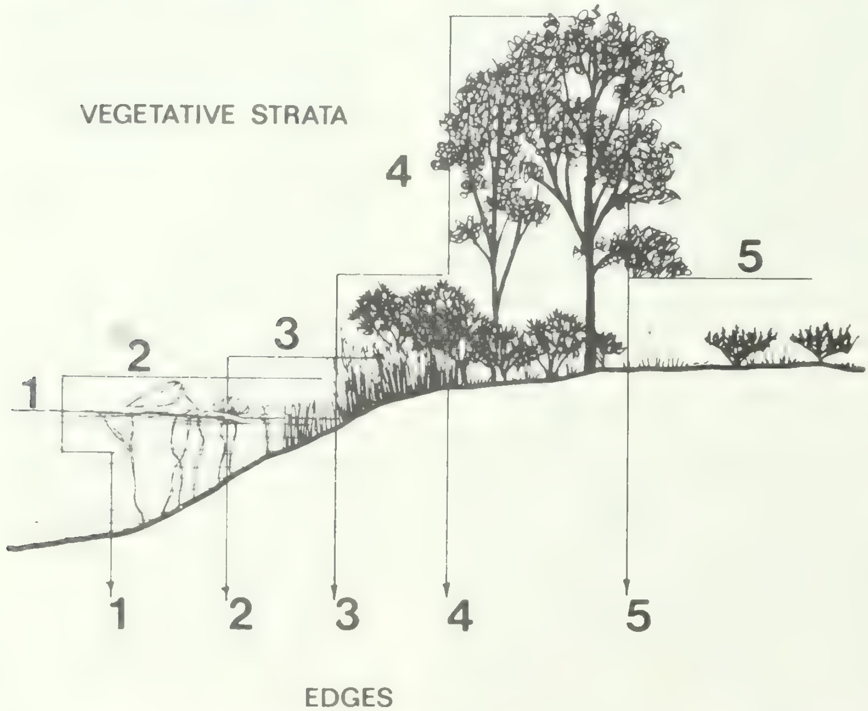


Figure 8.—Riparian zones frequently have a high number of edges and strata in a comparatively small area. This produces habitat for a greater number of species, reflecting the diversity of plant species and community structure.

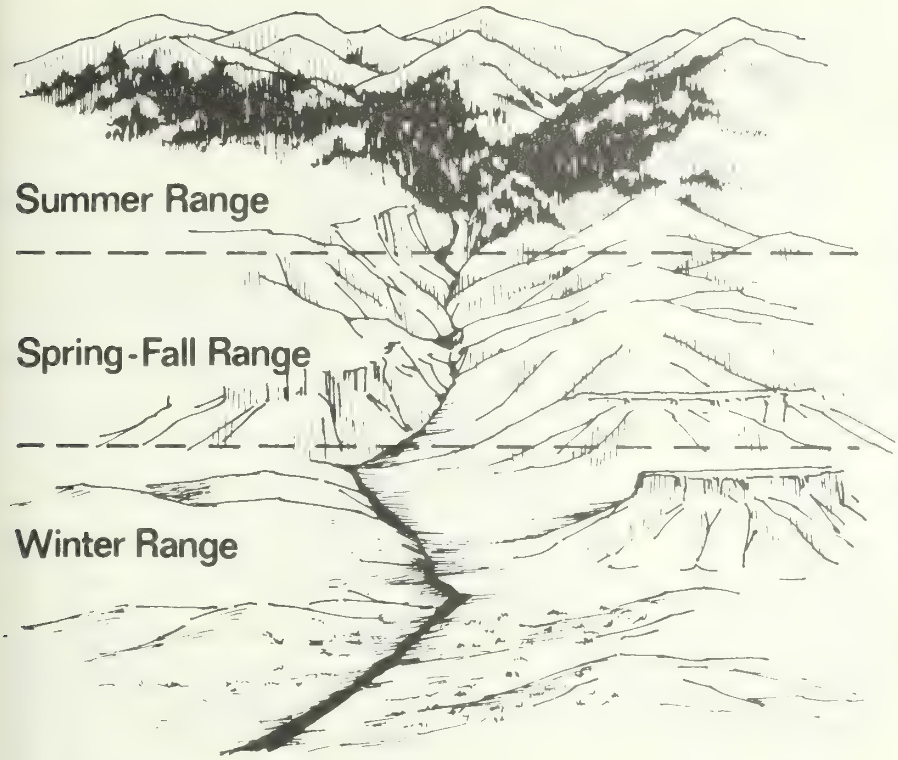


Figure 9.—Riparian zones along rivers and streams are frequently used as migration routes by wildlife. A migration corridor used by mule deer (*Odocoileus hemionus*) between summer range at high elevation and winter range at low elevation is illustrated.

6. The microclimate of riparian zones is different from that of the surrounding rangelands due to increased humidity, a higher rate of transpiration, more shade, and increased air movement. Some wildlife species are attracted to this microclimate. Mule deer (*Odocoileus hemionus*) spend a disproportionate amount of time in such areas due to the presence of cover that helps to maintain homeostasis or a condition where energy expenditure is minimized (see Thomas et al. 1979b for a review of this concept). The attraction of deer, elk, and other wild and domestic ungulates to these areas is caused by the abundance of thermal cover and the microclimate produced by that vegetation.

7. Riparian zones along intermittent and permanent streams and rivers provide migration routes for wildlife, such as birds, bats, deer, and elk (Stevens et al. 1977, Wauer 1977). In the case of deer and elk, such areas are frequently used as travel corridors between high elevation summer ranges and low elevation winter ranges (fig. 9).

8. Riparian zones, particularly along rivers and streams, may serve as forested connectors between habitats. Wildlife may use such riparian zones for cover while traveling across otherwise open areas. Some species, especially small mammals and birds may use such routes in dispersal from their original habitats caused by population pressure or food, water, or other shortage. The riparian zones provide cover and often provide food and water during such movements (fig. 10).

SENSITIVITY TO DISTURBANCE

Riparian zones occupy relatively small areas and should be considered vulnerable to severe alteration. Because of the distinct vegetative community and the structure of riparian zones, they must also be considered fragile. The more mature the vegetative complex of the riparian zone, the more apt it is to assume distinct edges and strata that intensify edge-effect and increase diversity. This mature condition is sensitive to management activities that occur within the riparian zone itself or on the surrounding rangeland (fig. 11).

The sensitivity of the vegetatively mature riparian zone as wildlife habitat can also be attributed to its distinct microclimate. Such

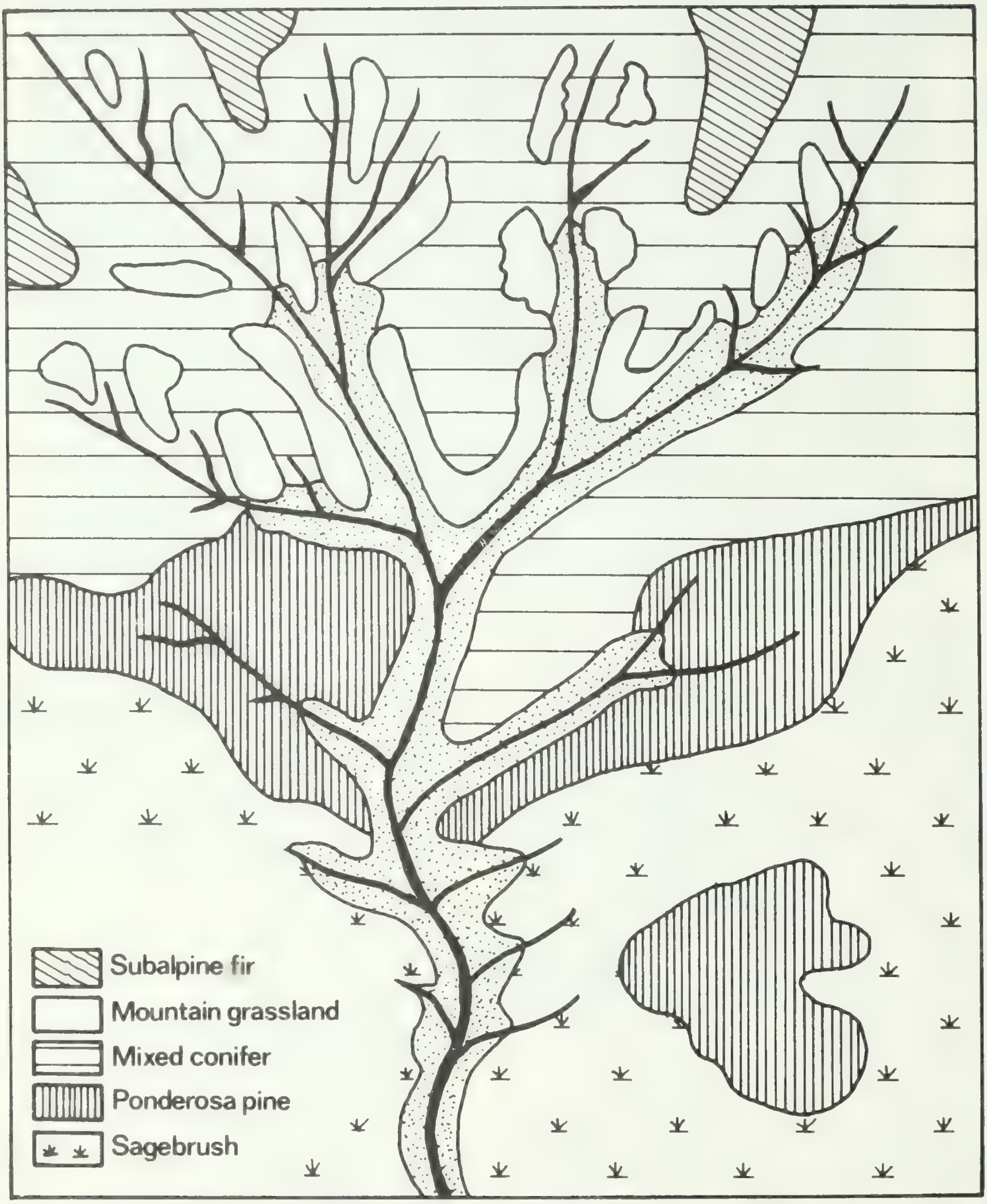
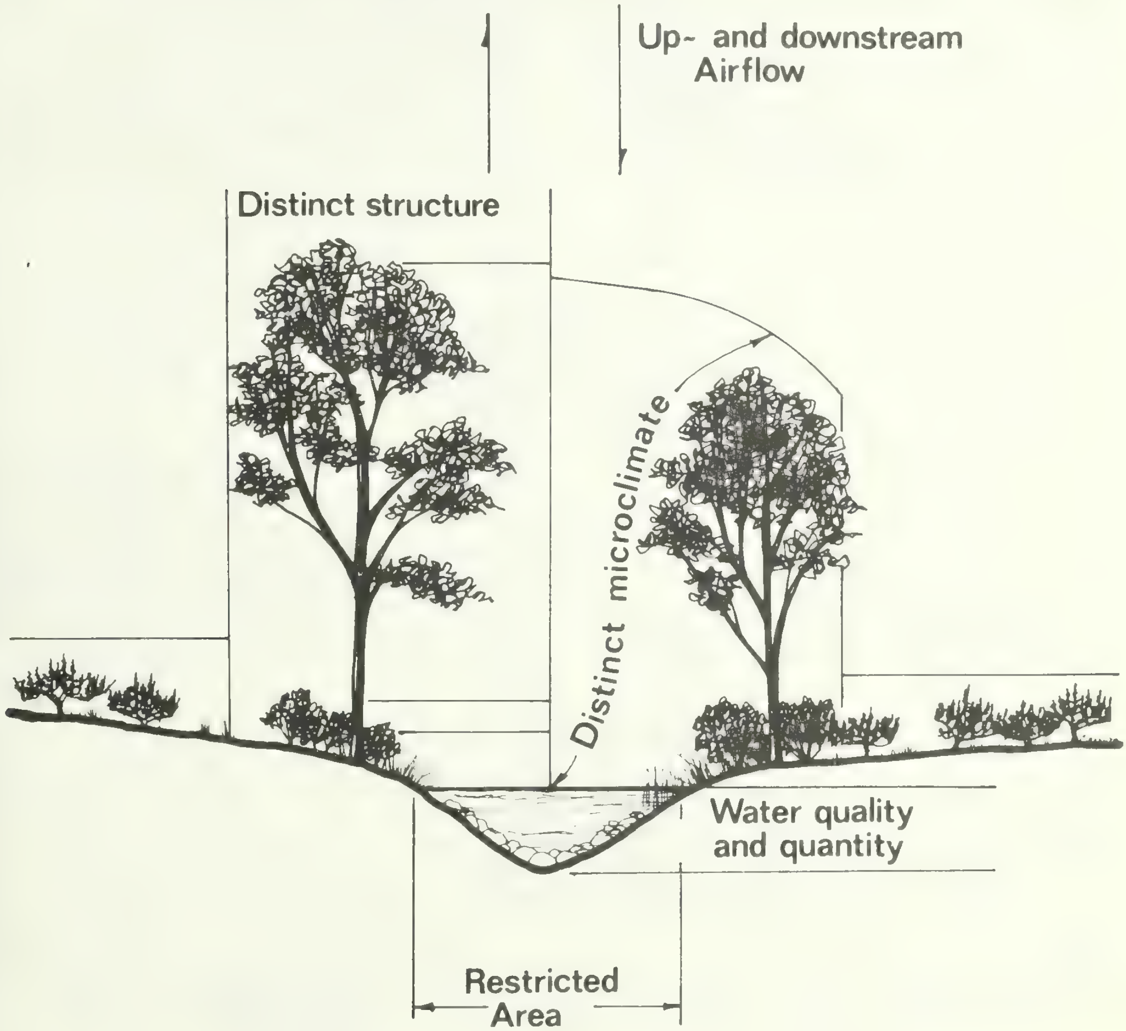


Figure 10.—Riparian zones along rivers and streams serve as connectors between habitat types; they provide cover, food, and water as the animals move from one location to another.

Figure 11.—Riparian zones must be considered as "delicate" due to the combination of restricted area, distinct microclimate, vegetative structure and composition, and water quantity and quality.



sensitivity includes both the terrestrial portions of the riparian zone and the characteristics of water quality (including temperature) of the associated aquatic zone (Boussu 1954, Gunderson 1968, Tuinstra 1967). Changes in the canopy cover can alter these characteristics markedly (Brown et al. 1971, Brown and Krygier 1967, Collings and Myrick 1966, Cordone and Kelley 1961, Meehan 1970). For example, an increase of a few degrees in water temperature may eliminate a stream as a trout fishery.

MANAGEMENT CONSIDERATIONS

Riparian zones are so different from one another that generalized animal-to-habitat relationships are difficult to develop for these areas. To do a good management job with such areas, one must derive a specific set of relationships for each particular case. Rangeland managers should consult both fishery and wildlife biologists when management activities are planned within the riparian zone. The following considerations can be helpful:

1. Road construction in riparian zones will lessen the effectiveness of the zone as habitat for many wildlife species (fig. 12). This results from both the alteration in the vegetative complex and in the increased disturbance from traffic along the road. Increased sedimentation from road construction may be detrimental to water quality and hence to aquatic life. Many streams in managed rangelands are already paralleled by roads. Each time a new streamside road is considered, managers need to determine how much riparian habitat will be seriously impaired by such roads. This can be done by comparing the percent of streams with roads alongside of them with the percent of streams without roads. Road construction probably has a more critical and long-lasting impact on riparian zones than any other management activity.

2. The narrower the riparian zone the more easily it is altered by management action.

3. Construction of campgrounds in riparian zones enhances the opportunity for human-wildlife contacts but simultaneously decreases effectiveness of the riparian zone as wildlife habitat due to the disturbance by humans, trampling, soil erosion, compaction, and loss of vegetation (Aitchison 1977, Aitchison et al. 1977, Settergren 1977).

4. Improper grazing practices in riparian zones can reduce water quality, eliminate streamside shrubs, cause soil compaction, accelerate erosion, and breakdown streambanks (Ames 1977, Buckhouse and Gifford 1976, Coltharp and Darling 1973, Diesch 1970, Marcuson 1977, Winegar 1975). Proper grazing management should include particular attention to insuring the welfare of riparian zones.

If livestock grazing is to take place in a riparian zone, the environmental impact on the zone should be carefully evaluated. The heavier the grazing and the more prolonged the grazing period the more severe will be the impacts (fig. 13). The environmental impacts of grazing in such zones may be magnified be-

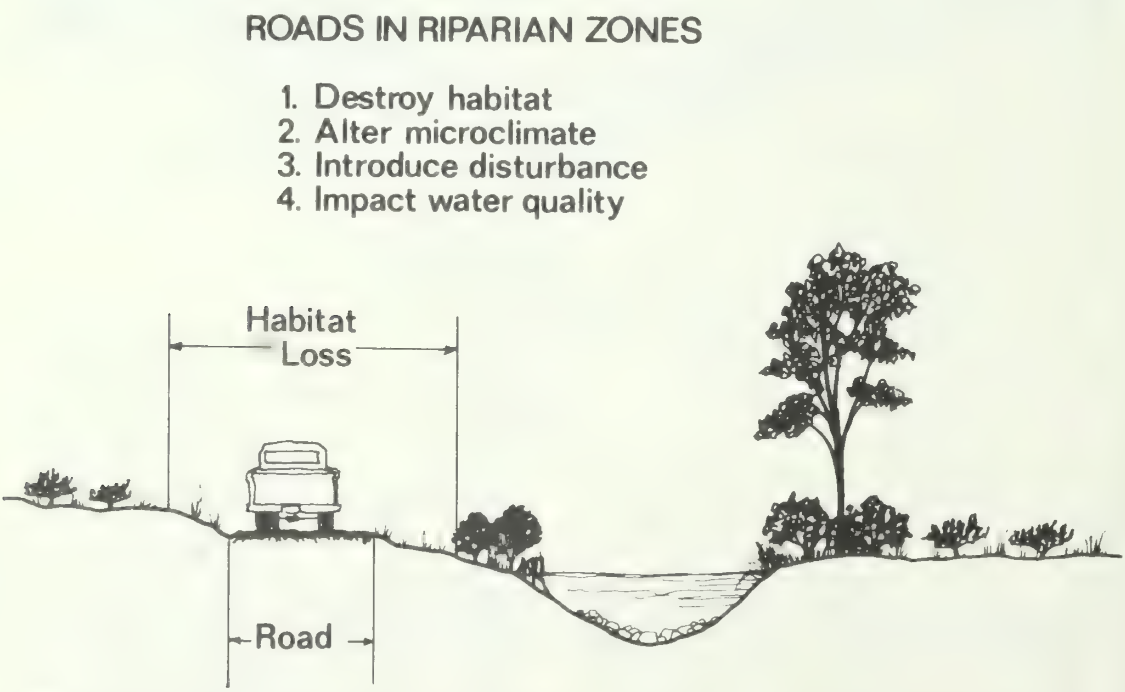


Figure 12.—Road construction in riparian zones reduces their usefulness as wildlife habitat. Roads in riparian zones: (1) alter vegetative structure, (2) alter microclimate, (3) reduce the size of riparian zones, (4) disturb the wildlife, (5) impact water quality in the aquatic zone, and (6) destroy the wildlife habitat.

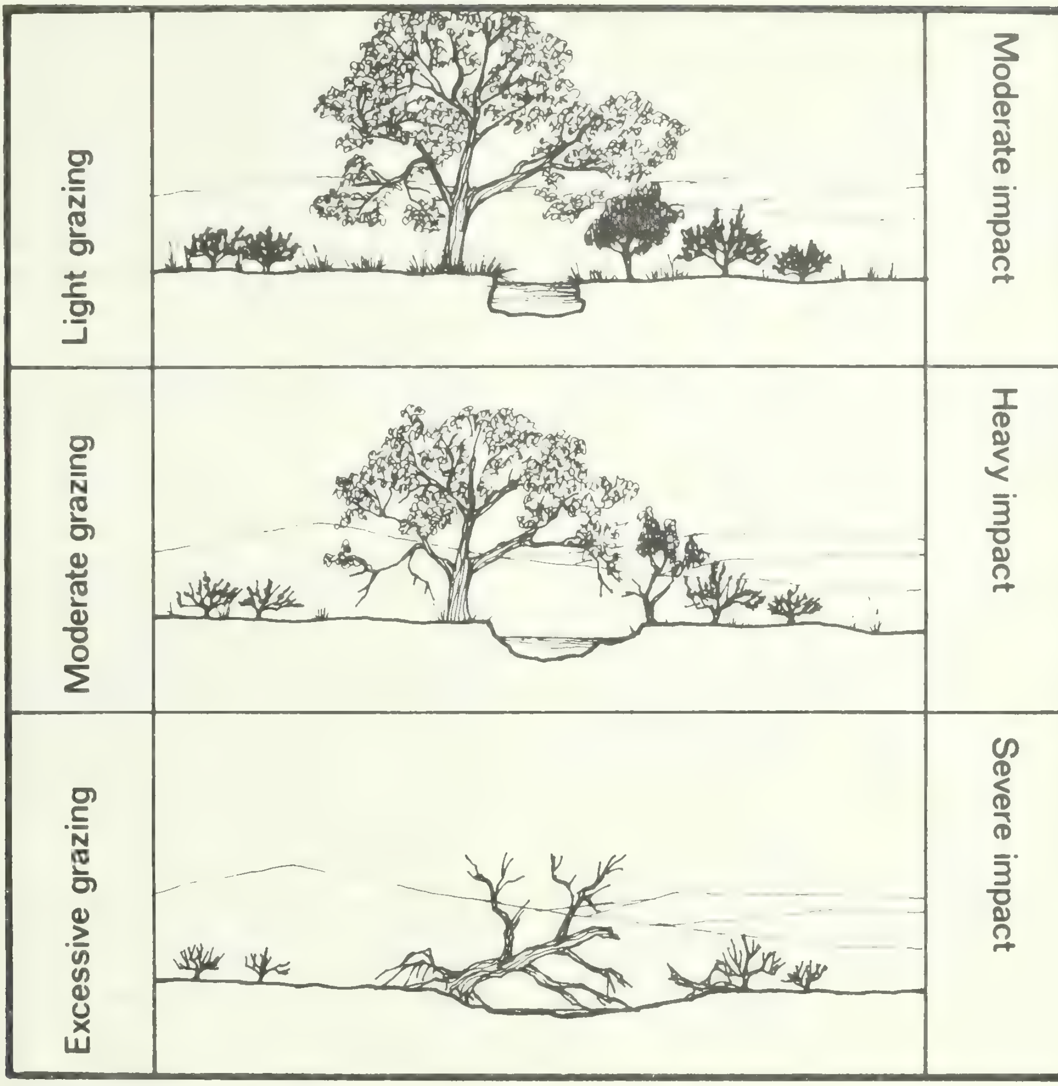


Figure 13.—When livestock are grazed in riparian zones, consideration of environmental impact is even more important than usual.

cause of the sensitivity of the microclimate and water temperature to increases in solar radiation reaching the ground or water surface. Some erosion disturbances are multiplied by proximity to the riparian zone. The key to prevention of surface erosion is the prevention or lessening of overland flow which is related to infiltration of precipitation. Infiltration may be enhanced by the maintenance of plant cover, both alive and dead. Under excessive grazing, livestock not only remove protective ground cover but also compact the soil, both of which accelerate erosion (Dambach 1944, Satterlund 1975).

Springs and seeps are often associated with relatively small, wet meadows. These meadows are critical to the existence of animals such as the montane vole (*Microtus montanus*) which, in turn, is food for many other vertebrates. Satterlund (1975, p. 24) observed:

> Meadows along stream channels are likely to be among the most productive parts of the range [in terms of livestock forage] because of the greater amount of water available for plant growth. Further, this same

> moistness makes them more susceptible to compaction. And finally, most animals [livestock] prefer to stay near available water, so this area receives the greatest impact of animal use. Therefore, these areas are key considerations in the prevention of erosion.

Development of seeps and springs for livestock (collecting the water into tanks and troughs) usually lessens the habitat value for wildlife (Heady and Bartolome 1977, USDA Soil Conservation Service 1967). When developing seeps and springs, one can increase values to wildlife by fencing the meadow surrounding a spring or seep to exclude livestock and piping the necessary water outside of the exclosure into troughs or other storage facilities (fig. 14). Small, wet meadows can also be created by piping overflow water from livestock troughs into fenced areas thereby creating and maintaining such meadows. A combination of the above techniques will provide the greatest area of "wet" habitat and, therefore, the greatest production of these rare and highly productive wildlife habitats.

5. Location of water impoundments are important if maximum benefits to wildlife are to be realized. Some areas which potentially receive the heaviest animal use are mature and decadent stands of western juniper (*Juniperus occidentalis*) and curlleaf mountain-mahogany (*Cercocarpus ledifolius*), cliffs, and edges between plant communities or structural conditions within plant communities (Maser et al. 1979, Maser and Gashwiler 1978, Thomas et al. 1978, Thomas et al. 1979c). Where water is a limiting factor, wildlife habitat may be created or enhanced by proper placement and design of water impoundments.

6. Although man-caused debris should be removed, a water source should not be "overcleaned." Leave moderate amounts of stable debris intact since it serves as critical, small habitats—usually for reproduction of small animals.

7. Recreational use per unit area of the riparian zone is many times that of other vegetative types (Heberlein 1977, Lewis and Marsh 1977, USDA Forest Service 1977). The impact of such use on wildlife varies with the season and type, intensity, and duration of use (Kuska 1977, Pfister 1977). Construction of trails, picnic tables, and docks encourages recreational use and increases the potential for conflicts with wildlife welfare.

8. Range management activities that take place outside the riparian zone may have impact on the riparian zone itself by changing the quantity and quality of water entering and in-

Figure 14.—Wildlife habitat can be maintained and/or enhanced by fencing a meadow surrounding a spring or seep to exclude livestock. The necessary water can then be piped outside of the exclosure into troughs, and by piping overflow water from livestock troughs into fenced areas, small, wet meadows can be created and maintained.

fluencing the riparian zones (Buckhouse 1975, Environmental Protection Agency 1976). Of the many factors that influence the amount of surface erosion and subsequent water quality, some can be controlled through management action, and the most important action is the maintenance of appropriate vegetative cover and soil conditions (Satterlund 1975). These influences may involve changes in suspended solids, nutrients, electrical conductance, and minerals as well as water temperature and water volume (Hibbert et al. 1974, 1975, Sharpe 1975). Leopold (1941, p. 17) put it this way: "Soil and water are not two organic systems, but one. Both are organs of a single landscape; a derangement in either affects the health of both...."

9. Any grazing management scheme that is instituted with the idea of preserving, enhancing, or reestablishing woody vegetation along streamsides or other riparian zones must consider the physiology of these plants and their response to grazing. Standard grazing systems, such as continuous rest rotation or deferred rotation (Heady 1975), in various forms, have generally been developed considering only the production and maintenance of forage plants—primarily grasses and forbs. It is likely that the application of such systems to maintain woody streamside vegetation and streambank integrity will not be satisfactory until the physiology of shrubs and trees is given consideration equal to forage plants.

Information on how grazing systems may be used to accomplish such goals as maintenance of woody streambank vegetation and the prevention of bank crumbling and soil compaction is only now being derived by experience and research. It is likely that special systems may have to be instituted, such as six or more pastures in the rotation grazing systems (compared to the presently standard two to five pastures) or complete protection for some period coupled with restricted grazing after satisfactory conditions are achieved.

"Business as usual" has resulted in deterioration of many riparian wildlife and fish habitats. New approaches to grazing management in riparian zones may be required to restore or maintain the fish and wildlife habitat values of this most critical zone.

A "RED FLAG" FOR RIPARIAN ZONES

The riparian zone is the most important wildlife habitat type in the managed rangelands. It is also the area of maximum potential conflict between users of timber, grazing, recreation, water, and wildlife resources. Riparian zones are usually quite sensitive to management activities and should be cautiously managed (Beschta 1978). As each riparian zone is somewhat different, the land manager should consult a wildlife biologist and a fishery biologist during the planning process if fish and wildlife welfare are objectives of management. The purpose of this chapter has been to raise a "red flag" where riparian zones are concerned. Habitat alterations will affect wildlife far more than indicated by the proportion of the total area disturbed.

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WILDLIFE HABITATS IN MANAGED RANGELANDS — THE GREAT BASIN OF SOUTHEASTERN OREGON

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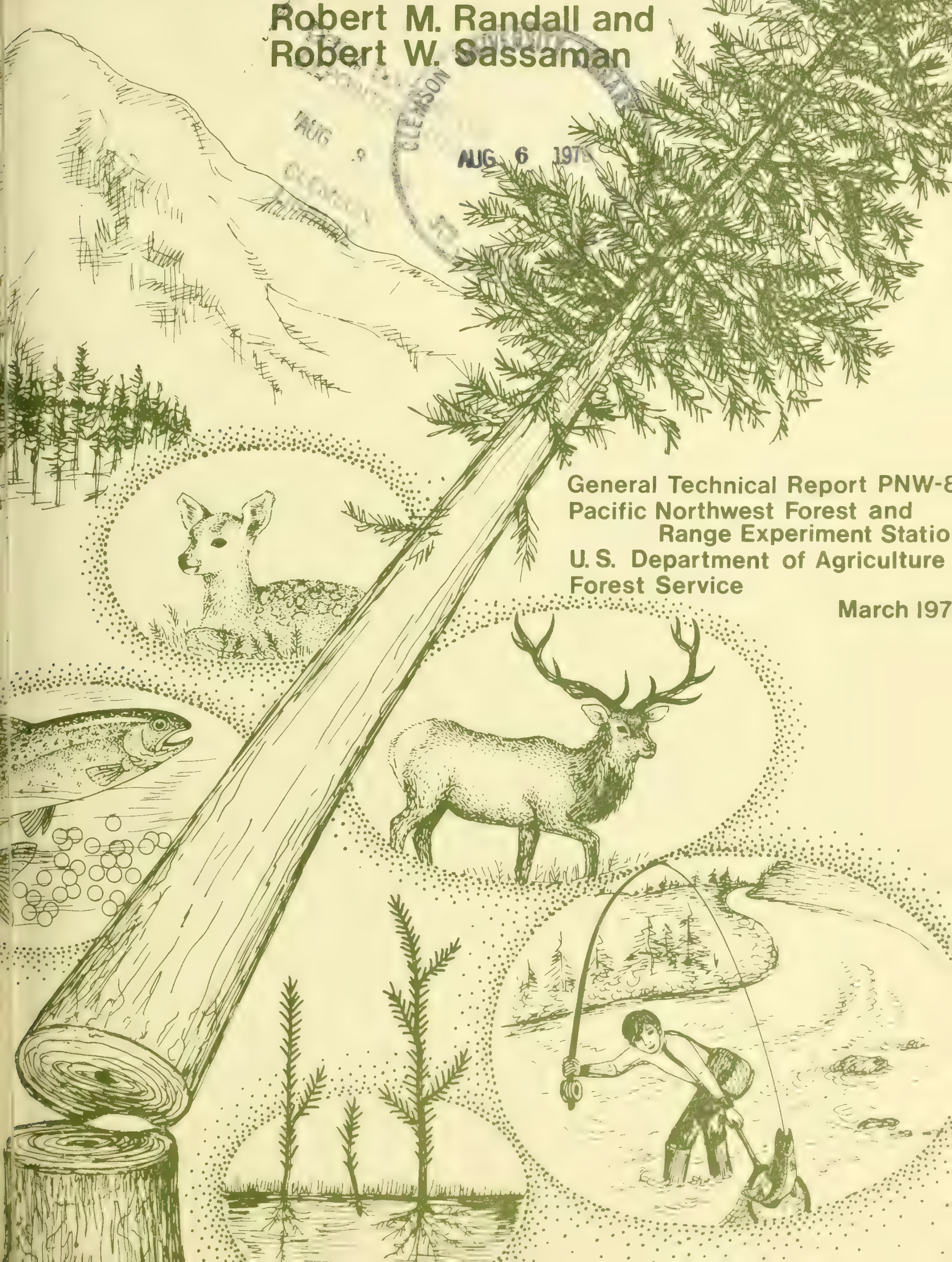
NTIFYING AND EVALUATING ENVIRONMENTAL ACTS ASSOCIATED WITH TIMBER HARVEST IEDULING POLICIES

Robert M. Randall and
Robert W. Sassaman



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ABSTRACT

Expected impacts on the ecosystem and nontimber benefits (that is, people's use of the resources--recreation, hunting, fishing, swimming, etc.) resulting from alternative timber harvest scheduling policies are identified and evaluated for the Mount Hood National Forest. Environmental criteria are established and used in evaluations of timber harvest and management data.

KEYWORDS: Logging operations analysis/design, amenity values (forest), ecosystems, environment, Oregon (Mount Hood National Forest).

CONTENTS

INTRODUCTION

Early in 1975, the Chief of the Forest Service initiated a study of the consequences that could be expected if the Forest Service were to depart from its harvest scheduling policy of nondeclining even flow. The study was accomplished in 18 months by a team of economists from the Pacific Northwest Forest and Range Experiment Station and representatives from other Experiment Stations and the academic community. The result was a report to the Chief, the "Timber Harvest Scheduling Issues Study."[1]

In brief, the study examined issues involving harvest scheduling alternatives, investment and utilization levels, and size of planning unit. Central to the study of harvest scheduling alternatives was an evaluation of social consequences expected if policy were to change; 13 consequences were identified and evaluated.

In this paper, we describe the procedures used to evaluate two of these consequences, impacts on the forest ecosystem and impacts on nontimber benefits. Nontimber benefits are derived from nontimber goods and services produced by the forest resources; for example, recreation, hunting, fishing, swimming, etc.

These two consequences were studied because any change in harvest scheduling or investment policy by an organization as large as the Forest Service results in impacts on the environment and the social uses of the nontimber resources. For example, changes in the rate of timber cutting, in silvicultural practices, and in the rate of road construction can be expected to produce impacts on the forest ecosystem with subsequent effects on resource supplies and uses. The purpose of these studies was to find out what impacts on the ecosystem and nontimber benefits might be expected and the magnitude of such impacts.

Specific objectives were to: (1) identify and estimate the magnitude of impacts on the forest ecosystem and on nontimber benefits caused by changes in Forest Service harvest scheduling policies and (2) evaluate the importance of these impacts in terms of criteria based on environmental standards and on social uses.

This paper describes the approach used to identify, estimate, and evaluate impacts and presents some of the results for analysts and land use planners who must assess environmental impacts and present them in a comprehensible form to decisionmakers.

Part 1 describes timber harvest scheduling alternatives and investment levels and the procedures used to identify, estimate, and evaluate impacts caused by these alternatives. Part 2 describes the criteria selected to evaluate each impact. Part 3 describes the results of the evaluation for one National Forest.

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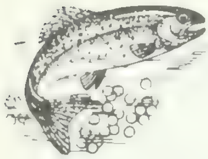
[1] U.S. Department of Agriculture, Forest Service. 1976. Timber harvest scheduling issues study. 292 p. Unpublished. Washington, D.C.



PART 1. ALTERNATIVES AND PROCEDURES

Alternative Harvest Schedules

Six harvest scheduling alternatives were evaluated; the procedures are outlined in this paper. The "Timber Harvest Scheduling Issues Study" (see footnote 1) had eight alternatives; however, the computer runs from two of these alternatives were not ready when specialists were convened to evaluate impacts and they are not included here since they were evaluated under different procedures. The six alternatives are described below:

A. *Nondeclining even flow* is the current Forest Service policy. It maximizes the first decade harvest, subject to no decline between decades. Harvest may rise but will not decline between decades.

B. *Conversion period even flow* was Forest Service policy prior to nondeclining even flow. It maximizes the first decade harvest subject to even flow for the first rotation only, followed by harvest at the resulting sustained-yield level. Harvest may neither rise nor decline during the first rotation. This policy may result in a drop in harvest level after the first rotation.

C. *Five-percent declining flow* maximizes the first decade harvest, subject to a maximum decline of 5 percent between decades. This alternative is likely to result in higher initial harvest levels.

D. *Ten-percent fluctuating flow*, as with alternative C, provides greater flexibility than strict even flow (alternatives A and B) does to vary the harvest to increase total yield. This alternative maximizes total harvest over the planning period (300 years), subject to a maximum fluctuation of ± 10 percent around the conversion period average.

E. *Area Control* attains a regulated forest more quickly than other alternatives do. Harvest is maximized over the first decade, subject to harvest cuttings of an equal area each decade. Volume flows can be erratic from decade to decade.

F. *Price-controlling flow* is the scheduling of harvests so as to counter long-term upward trends in national wood product prices. The objective is to benefit consumers by harvesting old growth at a faster rate to dampen the trend of rising wood product prices.

Investment Assumptions

In the "Timber Harvest Scheduling Issues Study" assumptions were made about the silvicultural practices that would be carried out in the future. Since these assumptions are speculative, two sets of assumptions were developed: a "low" level investment estimate about what might be done in the future and a "high" level investment estimate including a wider range of practices. These assumptions were evaluated for their impact on the forest ecosystem and on nontimber benefits.

Investment assumed	Investment level: Low	High
Planting "hard core" backlog areas	X	X
Planting harvest areas with:		
Regular stock	X	
Genetically improved stock		X
Stocking control		X
Commercial thinning	X	X

Study Procedures

Three kinds of data were needed to evaluate impacts: a description of the nature and estimate of the extent of management activities for each alternative and investment level; a description and estimate of magnitude of actual impacts on the ecosystem and nontimber benefits caused by management activities; and an evaluation of the importance, in social terms, of the impacts. This section describes the procedures used to obtain these data.

Description and Estimates of Management Activities

The Mount Hood and Ochoco National Forests were chosen as case studies for obtaining information about the nature and extent of management activities that would occur with each harvesting alternative. The information needed was provided by each Forest from Timber RAM (Resource Allocation Method) computer runs.[2] Only data for Mount Hood will be presented. Tables 1 and 2 summarize the pertinent management activities information provided by the Mount Hood National Forest. All data in tables 1 and 2 were a result of the Timber RAM program, except for road construction which was independently calculated. A similar format was used in analysis of impacts on the Ochoco National Forest.[3]

Table 1 shows figures for Mount Hood first at a low investment level; table 2, at a high investment level. The total area used in calculating the regulated harvest was 696,015 acres. This area does not include wilderness or other special areas devoted to nontimber uses.

Description and Estimation of Impacts on the Ecosystem and Nontimber Benefits

For information on impacts, specialists representing each resource area were either called together to comprise evaluation panels or were contacted individually.[4] The specialists were shown the data in tables 1 and 2. They were asked to describe the kinds of impacts and to estimate the levels of impacts on the ecosystem and nontimber benefits likely to occur as a result of changing from the current policy to one of the alternatives.

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[2] Navon, Daniel I. 1971. Timber RAM...a long-range planning method for commercial timber lands under multiple-use management. USDA For. Serv. Res. Pap. PSW-70, 22 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Timber RAM is a long-range planning method using linear programing for scheduling harvesting and reforestation on commercial forest lands under multiple-use management.

[3] Persons interested in the evaluation of impacts for the Ochoco National Forest should see background report 20, "Effects of harvesting alternatives on forest ecosystems" (36 p.), by Robert M. Randall, and background report 21, "Effects of harvest scheduling alternatives on nontimber benefits" (22 p.), by Robert W. Sassaman. These background reports are available from: Reprints, Graphic Information Systems, Inc., P.O. Box 23519, Portland, Oregon 97223; prices, postpaid to one address, are 15 cents per page for the first copy, 9 cents per page for additional copies.

[4] See appendix for list of panel participants.

Table 1--Average acres per decade by management activity and average miles of road constructed per decade for 6 policy alternatives in the Douglas-fir zone of the Mount Hood National Forest,[1] low investment level

Policy alternative	Clear-cutting	Shelter-wood cutting	Commercial thinning	Road construction
				Miles
	SHORTRUN IMPACT Acres (in thousands) treated (Average of 1st 3 decades)			
A Nondeclining even flow	43.9	14.7	43.7	243
B Conversion period even flow	44.2	14.7	43.7	243
C 5-percent declining flow	54.4	18.1	43.7	281
D 10-percent fluctuating flow	48.9	16.3	43.7	261
E Area control	41.4	13.8	42.5	[2]
F Price controlling flow	101.4	33.8	43.7	456
	LONGRUN IMPACT (10 DECADES) Acres (in thousands) treated (Conversion period average per decade)			
A Nondeclining even flow	41.8	13.9	127.0	151
B Conversion period even flow	41.8	13.9	127.0	151
C 5-percent declining flow	42.2	14.0	133.5	151
D 10-percent fluctuating flow	42.3	14.1	130.5	151
E Area control	41.4	13.8	95.6	[2]
F Price controlling flow	46.4	15.5	144.7	151

[1] Total managed area, 696,015 acres.

[2] Data not available.

Impact estimates were subjectively developed. Panelists estimated impacts on the basis of the acres harvested and treated per decade and the miles of road constructed. They felt that acres entered and miles of road constructed were better indexes of impacts than was volume harvested per decade. Because information linking the acres designated for harvest by the RAM model and the actual location of these acres on the ground was lacking, panelists had to make broad estimates of the impacts on the ecosystem and nontimber benefits.

Evaluation of Impacts

To evaluate impacts on the ecosystem, panelists were asked to judge whether an expected change in policy would produce

Table 2--Average acres per decade by management activity and average miles of road constructed per decade for 6 policy alternatives in the Douglas-fir zone of the Mount Hood National Forest,[1] high investment level

Policy alternatives	Clear-cutting	Shelter-wood cutting	Commercial thinning	Precom-mercial thinning	Road con-struction
					Miles
		SHORTRUN IMPACT			
		Acres (in thousands) treated			
		(Average of 1st 3 decades)			
A Nondeclining even flow	69.5	23.1	57.2	50.7	377
B Conversion period even flow	69.4	23.2	57.4	51.1	377
C 5-percent declining flow	79.8	26.5	57.2	65.2	415
D 10-percent fluctuating flow	73.7	24.6	57.1	52.0	392
E Area control	52.8	17.6	64.3	56.7	[2]
F Price controlling flow	106.7	35.6	57.1	62.5	515
		LONGRUN IMPACT (13 DECADES)			
		Acres (in thousands) treated			
		(Conversion period average per decade)			
A Nondeclining even flow	56.8	18.9	178.3	59.2	196
B Conversion period	56.0	18.7	169.0	68.3	196
C 5-percent declining flow	63.2	21.1	184.2	59.2	196
D 10-percent fluctuating flow	60.8	20.3	181.8	55.1	196
E Area control	52.8	17.6	179.0	62.2	[2]
F Price controlling flow	64.6	21.6	192.1	57.3	196

[1] Total managed area, 696,015 acres

[2] Data not available.

an adverse or beneficial impact as measured against various environmental standards. They were also asked to judge whether the impact would be of minor or major social concern. When an impact on the ecosystem was of major concern, the changes produced could be expected to require additional costs to restore the ecosystem element to its original condition, change use patterns, violate legal requirements, or draw the attention and concern of interest groups or the general public. An impact of minor concern was a change in the ecosystem that might be noticed by the trained eye but would not likely produce any of the four results listed above. Impacts were beneficial when a policy change produced impacts that moved in the direction of meeting environmental standards or surpassing them. Impacts were adverse when policy changes produced impacts that moved away from environmental standards. Panelists used the nondeclining

even flow alternative at a low investment level as the base for evaluating impacts.

To record the impacts of alternative harvest schedules on the various ecosystem criteria, we used a plus sign (+) for beneficial impacts and a minus sign (-) for adverse impacts. "N.C." indicated no change, 1 indicated a minor impact, and 2 indicated a major impact (table 3).

The study of impacts on nontimber benefits was carried out in conjunction with the ecosystem study to avoid duplication of effort. Panelists identified and estimated the impacts of timber harvest alternatives in terms of supply or use levels of nontimber benefits.

The evaluation system for impacts on nontimber benefits was different from that for the ecosystem. For example, plus and minus signs indicated increases or decreases in supply or use levels of the various nontimber benefits. The number 1 indicated impacts did not exceed a "threshold of concern" (TOC); 2 indicated impacts exceeded a TOC.

Threshold of concern is associated with a benchmark level of social concern that, if exceeded, will draw the attention and/or concern of interest groups or the general public, cause a noticeable change (positive or negative) in use patterns, or have an effect on the costs of maintaining the ecosystem. The important point with this concept is that small changes may be unnoticed or may be observed with some degree of indifference, but at some point in the range of social impacts, people take notice. They often become motivated to either take advantage of an impact, as in the case of increased opportunities for dispersed recreation, or take action to reverse the trend of impacts if they are negative.

As with the evaluation of impacts on the ecosystem, the present timber harvest schedule with low investment was used as a base for comparison with the other alternatives (table 4). The impacts recorded in the tables are changes from the base level. It is important to recognize that the base level is in no sense an ideal. The base is merely used for comparison. There may be adverse effects associated with the base level.

In evaluating impacts at the high investment level, panelists wanted to know what to assume about the proportion of the increased funding that would be allocated to environmental protection and the production of nontimber benefits. Panelists were told to assume that "high investment" refers only to investments for timber production. Expenditures, however, to mitigate adverse environmental impacts associated with timber management would be continued and increased but only in *proportion* to increased timber harvest levels. Therefore, increased investment in timber management does not reflect an increased emphasis on protection of nontimber resources nor does it mean the production of nontimber benefits will be increased.

Table 3--Relative impacts of timber harvest scheduling alternatives on various ecosystem criteria for the Douglas-fir zone of the Mount Hood National Forest compared with nondeclining even flow at the low investment level[1]

Harvest scheduling alternative and investment level	Water quality		Water quantity		Waterflow		Soil stability		Soil productivity		Wildlife habitat diversity		Fish habitat diversity	
	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run
A Nondeclining even flow:														
Low	0	0	0	0	0	0	0	0	0	0	0	0	0	0
High	-2	-2	+1	+1	-1	-1	-2	-2	-1	-1	-1	-1	-2	-2
B Conversion period even flow:														
Low	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
High	-2	-2	+1	+1	-1	-1	-2	-2	-1	-1	-1	-1	-2	-2
C 5-percent declining flow:														
Low	-1	N.C.	N.C.	N.C.	N.C.	N.C.	-1	N.C.	-1	N.C.	-1	N.C.	-1	N.C.
High	-2	-2	+1	+1	-1	-1	-2	-2	-1	-1	-1	-1	-2	-2
D 10-percent fluctuating flow:														
Low	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
High	-2	-2	+1	+1	-1	-1	-2	-2	-1	-1	-1	-1	-2	-2
E Area control:														
Low	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
High	-1	-2	+1	+1	-1	-1	-1	-2	-1	-1	-1	-1	-1	-2
F Price controlling flow:														
Low	-2	N.C.	+1	N.C.	-1	N.C.	-2	N.C.	-1	N.C.	-1	-1	-2	N.C.
High	-2	-2	+1	+1	-1	-1	-2	-2	-1	-1	-1	-1	-2	-2

[1] N.C. = no change; 1 = minor impact; 2 = major impact; + = beneficial impact; - = adverse impact; 0 = base alternative.

Table 4--Relative impacts of timber harvest scheduling
zone of the Mount Hood National Forest compared

Harvest scheduling alternative and investment level	Cold water fish populations		Domestic forage production		Opportunities for developed recreation		Opportunities for dispersed recreation		Natural-appearing forest landscape	
	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run
A Nondeclining even flow:										
Low	0	0	0	0	0	0	0	0	0	0
High	-2	-2	N.C.	N.C.	N.C.	+1	+2	+2	-2	-2
B Conversion period even flow:										
Low	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
High	-2	-2	N.C.	N.C.	N.C.	+1	+2	+2	-2	-2
C 5-percent declining flow:										
Low	-2	N.C.	N.C.	N.C.	N.C.	N.C.	+2	N.C.	-2	N.C.
High	-2	-2	N.C.	N.C.	N.C.	+1	+2	+2	-2	-2
D 10-percent fluctuating flow:										
Low	-1	N.C.	N.C.	N.C.	N.C.	N.C.	+1	N.C.	-1	N.C.
High	-2	-2	N.C.	N.C.	N.C.	+1	+2	+2	-2	-2
E Area control:										
Low	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
High	-2	-2	N.C.	N.C.	N.C.	+1	+2	+2	-2	-2
F Price controlling flow:										
Low	-2	N.C.	+1	N.C.	N.C.	N.C.	+2	N.C.	-2	N.C.
High	-2	-2	+1	N.C.	N.C.	+1	+2	+2	-2	-2

[1] N.C. = no change; 1 = minor impact; 2 = major impact; 0 = base alternative;

alternatives on various nontimber benefits for the Douglas-fir with nondeclining even flow at the low investment level[1]

dustrial and nicipal water		Irrigation water		Recreational use of water		Deer and elk populations		Wildlife for viewing by the: Discriminating observer		General observer		Casual observer	
ort run	Long run	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run	Short run	Long run
0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2	-2	+1	+1	-2	-2	+2	-2	-2	-2	+2	+1	+2	-2
.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
-2	-2	+1	+1	-2	-2	+2	-2	-2	-2	+2	+1	+2	-2
-1	N.C.	N.C.	N.C.	-1	N.C.	+1	N.C.	-1	N.C.	+1	N.C.	+1	N.C.
-2	-2	+1	+1	-2	-2	+2	-2	-2	-2	+2	+2	+2	-2
C.	N.C.	N.C.	N.C.	N.C.	N.C.	+1	N.C.	N.C.	N.C.	N.C.	N.C.	+1	N.C.
-2	-2	+1	+1	-2	-2	+2	-2	-2	-2	+2	+2	+2	-2
.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.	N.C.
-1	-1	N.C.	N.C.	-1	-1	+1	-2	-1	-1	+1	+1	+1	-2
-2	N.C.	+1	N.C.	-2	N.C.	+2	N.C.	-2	N.C.	+2	N.C.	+2	N.C.
-2	-2	+1	+1	-2	-2	+2	-2	-2	-2	+2	+2	+2	-2

beneficial impact; - = adverse impact.

PART 2. CONSEQUENCES AND CRITERIA

Ecosystems

Discussion of the Consequences

The condition of the forest ecosystem is of considerable interest to segments of the public. Many people value the ecosystem for its own sake and are interested in and sometimes opposed to any changes that take place. Other people are not opposed to modifications of the forest ecosystem but are concerned about the effects that harvesting and management activity might have on both the shortrun and longrun flow of benefits and on forest productivity.

The public also recognizes that harvesting and management activities can have impacts on other areas too. An example of this is the smoke from slash burning that adds to pollution problems of urban and rural areas outside the National Forest.

To determine how the ecosystem would be affected by management activity, we divided it into subsystems. A subsystem was selected for study if it was the source of a socially valued output of the forest and if the harvest scheduling alternatives and investment levels would be expected to affect this subsystem.

The subsystems were: (1) water, (2) soils, (3) fish and wildlife, (4) air, and (5) vegetation.

Each subsystem is vital in the production of multiple goods and services from the forest. They are all affected one way or another by forest management activities.

Selection of the Criteria

The criteria and objectives listed below were developed from a review of literature related to laws pertaining to National Forest management and from discussions with specialists. The criteria are presented as nine formal statements to "maintain," "regulate," or "protect," etc. Each criterion embodies social objectives as well as a statement of commonly used measurement indexes. Readers interested in a further discussion of the legal or social background from which the objectives and criteria are derived should refer to background report No. 20 by Randall (see footnote 3, page 3). The objectives and criteria were to:

1. Maintain or enhance water quality--measured by sediment concentrations and water temperature.
2. Maintain or enhance water quantity--measured by acre-feet of waterflow from a given stream over a given period.
3. Regulate waterflow--measured by cubic feet of waterflow from a given stream over a given period.
4. Maintain or enhance soil stability--measured by inches per year of sheet erosion or cubic yards per square mile of mass wasting.
5. Maintain or enhance soil productivity--measured by compaction, in terms of percent reduction in macropore space, and by fertility, in terms of changes in available nutrients and moisture-holding capacity.
6. Protect and enhance threatened and endangered fish and wildlife species--measured in terms of populations per given species.
7. Maintain enough habitat diversity to accomodate the various fish and wildlife species living in a specified area--measured by acres of habitat type.

8. Maintain or enhance air quality--measured by particulate matter at a particular location over a given period.

9. Maintain vegetative cover that will provide options for the various multiple benefits society derives from the forest--measurable vegetative indicators might include species composition of trees and understory plants, stand age and density, successional stage of forest, and proportion of openings to solid tree cover.

Nontimber Benefits

Discussion of the Consequences

In our evaluation of potential impacts on nontimber benefits resulting from alternative timber harvest scheduling policies, we had to recognize that although forest products such as timber and forage are marketed for monetary returns, other products such as recreation, fish, and wildlife are not. Our evaluation, therefore, would have to rely on physical measures of benefits rather than financial measures.

Faced with the responsibility of evaluating alternatives in such a context, we needed to establish relationships between management activities and nontimber benefits. We devised a method to utilize the intuitive judgment and experience of nontimber resource specialists in identifying the levels of physical output associated with given levels of harvesting and in evaluating their importance.

A key step in our evaluation of impacts on nontimber benefits was the selection of criteria.

In selecting criteria, we identified the impacts we wished to measure with the help of specialists in appropriate disciplines. Our intent was to define criteria in terms that related to socially valued output. The nontimber resource specialists indicated that forest managers would be better equipped to judge potential impacts if they could relate them to a benchmark level of social concern. From this idea we developed the TOC concept described in part 1.

Selection of Criteria

Criteria were selected to measure expected levels of opportunities relative to current levels. We selected them to be used with data from any forest in the West; we recognized, however, that data from one forest are not necessarily applicable to other forests. Data should be analyzed on a forest-by-forest basis and applied only to subregions or groups of forests characterized by similar species composition and climate.

The categories used were: No change ("NC"), not exceeding threshold of concern ("1"), and exceeding threshold of concern ("2").

Criteria for nontimber benefits follow:

Anadromous and resident cold water fish populations.--This criterion is of concern to sportsmen and environmentalists. The level of fish populations is closely related to water quality conditions. If not carefully planned and executed, the construction and maintenance of roads, residue treatment, and timber harvesting operations can all have major adverse impacts on water quality and thus, fish habitat.

Domestic forage production.--Forested ranges represent a large forage resource in National Forests of the Pacific Northwest. Presently, most grazing occurs on forested ranges rather than in natural forest openings or

harvested areas. In 1975, about 90 percent of the domestic forage production in Region 6 occurred in the so-called ponderosa pine subregion, where forested ranges serve as summer ranges. The seasonal nature of these ranges enhances their importance, since a lack of summer grazing is often a limiting factor in cattle operations. Without adequate summer range grazing permits, many ranches cannot maintain the herds they are capable of supporting the rest of the year. In the Douglas-fir region, there are some possibilities that domestic livestock grazing may increase if harvesting of timber is accelerated in the future, but such impacts are largely uncertain as the increased harvests may occur in areas unsuitable for grazing.

Opportunities for dispersed recreation.--These opportunities are closely related to the miles of forest roads open to recreationists. In turn, the number of miles of usable road is affected by road maintenance (historically, recreation management has not been funded to do this) and the management philosophy toward dispersed recreation (scattered, individual outdoor recreation activities normally not identified with developed facilities) as a legitimate use of National Forests. The attitude and approach to dispersed recreation varies widely among forest administrators. Some encourage it, others do not. Statistics indicate it is the fastest growing form of recreation on most National Forests.

Opportunities for developed recreation.--Developed recreation facilities are usually located near major roads and attractions, such as lakes and streams. These opportunities are less affected by an expanding timber management road system than are opportunities for dispersed recreation.

Opportunities for viewing natural-appearing forest landscapes.--This criterion is closely linked to the type and extent of forest management activities. Extensive use of clearcutting is generally not conducive to a natural look; however, if clearcuts are limited in size and carefully placed, much can be done to soften their impact. Other silvicultural techniques, such as shelterwood cutting and thinning, leave trees standing after operations are through and thus give a more natural appearance, especially when viewed from a distance.

Water uses--industrial, municipal, recreational, and irrigation.--All these common uses of water are affected by the quality (mainly sediment content) and the quantity (mainly timing of flow) of available water. Water quality in watersheds is affected by the location and amount of site disturbance associated with forest management activities. Waterflow is closely related to the size of the area devoid of vegetation at any given time.

Deer and elk populations.--Populations of deer and elk are closely linked to the condition of their habitat. Adequate summer and winter range with sufficient conifers to provide cover are needed to maintain herd size. The ever-expanding road system which accompanies timber harvests has an impact on deer and elk by reducing cover and increasing human access. With loss of cover and increased access opportunities for hunters and the general public, bucks may be harvested in numbers too great to maintain breeding levels and just the presence of greater numbers of people may become a harrassment that lowers the general vigor of the herd.

Opportunities for viewing wildlife.--Viewers of wildlife are frequently classified as casual, general, or discriminating observers. The casual observer looks for deer, elk, or bear. The general observer spends considerable time in the forest trying to view a wide variety of species. The discriminating observer is after a glimpse of rare and unusual species. These observers will spend considerable time, effort, and expense to pursue their hobby. Forest management activities including road construction, affect wildlife populations by altering their habitat and increasing human harrassment.

Thresholds of Concern

The panels of resource specialists suggested that the following changes in levels of impact may represent the TOC for nontimber benefits in the Pacific Northwest: anadromous and resident cold water fish populations, 10 percent; domestic forage production, 20 percent; opportunities for developed and dispersed recreation, 15 percent; opportunities for viewing natural-appearing forest landscapes, 15 percent; industrial, municipal, irrigation and instreamflow uses of water--any change that exceeds present objectives for a prolonged period of time; deer and elk populations, 10-15 percent (or anytime the buck ratio drops below 15 percent); wildlife populations for the casual viewer, 10-20 percent; wildlife populations for the discriminating viewer--10-20 percent and 25-50 percent for the general viewer.

PART 3. EVALUATION OF IMPACTS ON ONE NATIONAL FOREST[5]

Tables 3 and 4 show the impacts on the ecosystem and on nontimber benefits resulting from six harvest scheduling alternatives and two investment levels for the Mount Hood National Forest in the Douglas-fir subregion.

The starting point or base for evaluation was the current Forest Service policy of nondeclining even flow (alternative A); in addition, we assumed a low level of investment. Panelists were quick to warn that current policies might lead to some undesirable effects if they were carried out for the long run; that is, there was room for improvement in present management practice. We asked panelists to use current policy and its trends, whether beneficial or adverse, as the base against which to evaluate other activities and investment levels. Thus, alternative A at the low level of investment in tables 3 and 4 appears as a row of zeros.

The following discussion is divided on the basis of impacts on the ecosystem and nontimber benefits. The purpose of the discussion is to describe the cause and nature of impacts and, in the case of adverse impacts, to suggest solutions.

[5]For discussion of impacts on both Mount Hood and Ochoco National Forests see the background reports by Randall and Sassaman mentioned in footnote 3, page 3.

Impacts on the Ecosystem

Water Quality

The major concern about water quality is the possibility of sediment entering streams. This likelihood increases as logging and particularly roadbuilding increase. Aside from any accelerated rate of harvesting, the panelists felt that the Forest Service could be headed for water quality problems under its present program. The problems may come in failure to meet water quality standards that are being formulated by various State agencies and the Environmental Protection Agency. A major uncertainty is how these regulations may affect silvicultural activities.

When we examine alternative harvest schedules, as shown in table 3, we see that water quality impacts depend in large part on the level of investment chosen. At low levels we will have little or no change except for alternative F where cutting is periodically high. At high investment levels, impacts become more serious.

In the short run, we can expect major adverse impacts with the accelerated harvesting and road construction associated with high investment levels. An exception is alternative E where activities do not accelerate until after the third decade. Adverse impacts are expected to take the form of reduced recreational opportunities, spoiled fish habitats, and violations of environmental laws and regulations.

In the long run, as the road system is completed, adverse impacts will be less, although the panelists thought that the high levels of final harvesting and thinning could still be a source of water quality problems.

The panelists suggested that adverse water quality impacts might be mitigated by improved harvest planning and by specialized equipment and harvesting systems. Of course, such measures will involve higher costs.

Water Quantity

Water yields are known to be influenced by forest management practices. The panelists agreed that clearcutting was the major practice that would influence water yield. The panelists felt, however, that even substantial increases in cutting would have at most a minimal effect on regional water supplies. Some localities might experience noticeable increases in yield, but the data are not sufficiently precise to identify these areas nor the magnitude of increase.

In water quantity, the harvest scheduling alternative chosen by the Forest Service does not seem to make much difference.

Waterflow

The major concern over water flows is storm runoff and its potential for damage to life and property through flooding. There is also concern for erosion of stream channels by unusually high water levels.

The panelists indicated that there was potential for localized onforest flooding that could result in damage to bridges, culverts, roads, and campgrounds. Even at current levels of management localized flood damages occur. Table 3 shows that for most alternatives at the low investment level, damages would not likely increase; but at the high investment level, we could expect more flood-induced damages in some localities.

Although local damage might occur, the potential for off-forest flooding was considered minimal even at the higher activity levels associated with the high investment assumption

Soil Stability

The major concern for soil stability is that erosion has adverse impacts on water quality and that landslides can damage property and at times are a threat to life. The problems with soil stability are especially aggravated by roadbuilding and, to a lesser degree, by harvesting--particularly on steep, unstable slopes. Erosion occurs even under natural conditions. As man intrudes, erosion can accelerate. The question is, how much will it accelerate?

As seen from table 3, major adverse impacts are correlated with the high level of investment and with the heavy periodic cutting patterns of alternative F at the low investment level. The panelists predicted longrun major problems with soil movements, mainly because of the combination of extensive road systems with heavy rainfall.

Soil Productivity

Soil productivity is a longrun concern of forest managers and of society. Some panelists expressed concern over current practices and their effects on productivity. Factors mentioned as having important impacts on productivity were drains on the nutrient budget of the soil and compaction. Reduction of residue was noted as an important management activity affecting nutrient levels, and use of harvesting machinery was seen as a major factor influencing soil compaction.

Low investment levels were not expected to result in any significant longrun change in current productivity trends. Shortrun reductions in productivity would be possible with alternatives C and F because of their higher cutting rates. These reductions would be minor, however. High investment levels were not seen as producing any major impacts although there might be minor losses in productivity.

Diversity of Wildlife and Fish Habitat

Wildlife.--We found that the impact evaluation used in table 3 was of limited usefulness in evaluating the impacts on diversity of wildlife habitat and on the status of threatened and endangered species; cutting can be accelerated and management investments intensified without closing habitat options if management is willing to maintain a variety of habitat types. We do not know whether the Forest Service's management of wilderness areas, foreground and middleground retention zones, streamside leave strips, and other environmental measures provides the habitat diversity necessary to prevent closing out options. If we assume that diversity is adequate, however, differences still exist between alternative harvest schedules.

In general, at low investment levels, accelerated cutting will create a larger number of habitat types and edge effects; however, the accelerated building of roads will increase man's harrassment of wildlife populations. At high levels of investment, we create a forest, a large portion of which is narrowly diversified. In terms of wildlife objectives, this narrowed diversity over large areas would not be desirable even if certain areas were reserved for specific wildlife habitats.

Fish.--Habitat diversity for Forest Service fisheries management essentially means protecting and enhancing habitat conditions conducive to stable or growing populations of warm water fish, cold water anadromous and resident

fish, and threatened and endangered fish species.

Panelists felt that present fish habitat management practices were insufficient to prevent gradual deterioration of habitat conditions. The major problem is stream sedimentation. There was a feeling that if current regulations and the best practices were vigorously carried out; adverse effects would be avoided under current policies. The reasons given for weaknesses in fisheries program were lack of funding and manpower to enforce regulations and less than enthusiastic cooperation from many operators.

Table 3 shows that at low levels of investment, the only major adverse impacts expected would be in the shortrun at the high cutting levels of alternative F. At high levels of investment, the panelists expected difficulties in maintaining the quality of fish habitat. With an extensive road system and a high level of harvesting activity, to keep sediment out of streams would be difficult, even with rigorous enforcement of regulations.

Threatened and Endangered Fish and Wildlife Species

Wildlife.--The comments about diversity of wildlife habitat apply here. A trend toward intensified management can increase diversity to some degree; carried too far, it will begin to close out options.

Two categories of threatened and endangered species must be considered--those established at the national level and those established at the State level. On the Mount Hood National Forest there were 5 threatened and endangered species classified by Federal law and 10 classified by State law at the time of the study. In the panelists' view, none of these species were in imminent danger of extinction on the Forest; however, there was concern over the possible future impact of conversion to intensified management.

Fish.--The panelists did not expect accelerating the harvest or intensifying management to be a major threat to the continued existence of any fish species found on the Mount Hood National Forest.

Air Quality[6]

Unlike controls over other impacts on the ecosystem, manage[illegible] have direct control (except for wildfires) over the source of smoke production. They make the decisions of whether or not to burn, the methods to use, and the timing. Once these decision[illegible] are made, the impact of resultin[illegible] smoke depends on the location of the fire, its duration, the concentration of pollutants in the smoke, and weather conditions.

Smoke produced by slash fires can add to pollution levels of both rural and urban areas, possibly causing pollution levels to exceed national standards for particulate matter in the air (the major air pollutant contributed by slash burning). Nation[illegible] standards are based on annual and 24-hour averages. Slash burning is not significant enoug[illegible] to cause violation of annual averages, but it certainly could cause levels in localities to exceed 24-hour averages.

In the short run, if we accelerate cutting or intensify management, we can expect a corresponding increase in the risks

[6] Owen Cramer, meteorologist, Pacific Northwest Forest and Range Experiment Station, was the primary contributor to this section.

of aggravating air pollution by slash burning. The extent to which this will happen depends on a combination of managerial skill, condition and amount of slash, weather, and pollution levels over populated areas.

In the long run, as management gradually becomes based on young-growth forests, we can expect residues and the air pollution problem to decrease. One negative element, however, is the increased risk of wildfire that may be associated with slash from precommercial thinning. This hazard will build as we move toward more intensive management.

Vegetative Character

Much of what was said in the section on diversity of wildlife habitat applies here. As we move toward intensified management of timber, we tend to undiversify the forest. Species composition is deliberately limited to one conifer or a few selected conifers. Successional stages at the beginning and end of a stand's life are eliminated. Openings in the stand are replanted to conifers. Although these actions may favor timber production and may not noticeably detract from water or recreation use, they can adversely affect certain grazing and wildlife uses.

Impacts on Nontimber Benefits

Anadromous and Resident Cold Water Fish Populations

Fish populations are directly affected by water quality. Sediment, a common indicator of water quality, is a byproduct of timber harvest practices, including road construction. Fish and watershed management specialists felt, however, that the degree of managerial emphasis (staffing and funding) placed on road maintenance and the enforcement of contract stipulations governing logging practices has an important bearing on water quality. In fact, the panelists felt that even a continuation of the present timber harvest policy would decrease fish populations in both the short run (three decades) and the long run (conversion period) unless funding were increased to mitigate adverse impacts. Table 4 shows major adverse impacts for any sizable increase in harvesting activity; however, with adequate funding and management, many of these impacts might be offset.

Domestic Forage Production

No significant impact on domestic forage production is expected in the Douglas-fir subregion of Region 6 under the present timber harvest scheduling policy or with any of the alternatives. Increases in forage production may occur because of alteration of species composition, but they are expected to be small and not to significantly affect use patterns.

Opportunities for Developed and Dispersed Recreation

None of the scheduling alternatives was expected to have a significant impact on opportunities for developed recreation. As the road system expands to accommodate increased harvests and investments in timber management, however, opportunities for dispersed recreation should increase significantly as shown in table 4.

Opportunities for Viewing Natural-Appearing Forest Landscapes

This criterion concerns the prevalence of forest areas with little apparent evidence of manmade manipulation of the landscape.

The panel of forest recreation specialists indicated a direct connection between this criterion and the total number of acres disturbed per decade. They felt that increased cutting levels or investment levels would seriously decrease opportunities for viewing natural-appearing forest landscapes in both the short run and the long run.

Industrial, Municipal, Irrigational, and Recreational Uses of Water

Industrial and municipal uses of water are directly affected by water quality. At the high investment level, all timber harvest alternatives, except area regulation, would create impacts that exceed the threshold of concern for industrial and municipal water in both the short run and the long run.

Impacts on irrigation water are related to quantity. None of the timber harvest alternatives create a significant impact on irrigation water.

In Region 6, recreational use of water relates directly to water quality and, to a much lesser extent, water quantity. Impacts recorded in table 4 indicate that at the high investment level all the timber harvest alternatives, except area control, create impacts that exceed the TOC.

Deer and Elk Populations

At the low investment level, panelists indicated that there would be a tendency for deer and elk populations to increase under alternatives that accelerated cutting rates. This would only be a shortrun effect. At a high investment level, with its larger timber harvest, panelists expecte significant increases in populations in the short run because of an expected increase in browse In the long run, however, populations would decline because of reduced cover and increased harassment.

Wildlife Populations for Viewing

Table 4 shows impacts differentiated by three categories of viewers. It is evident that increases in harvesting also produce increases in viewing opportunities for the general observer. These increases are especially evident at the high investment level and also as a shortrun effect for the high cutting rate alternatives at the low investment level.

Casual observers are expected to experience greater opportuniti for viewing in the short run; but in the long run, opportunities are expected to significantly decline, especially at the high investment level. This effect is closely related to the longrun decline of deer and elk populations at the high investment level.

Discriminating observers will experience diminished viewing opportunities. As cutting is accelerated and the forest more intensively managed, habitat for many species of wildlife will be reduced, severely modified, or eliminated.

EVALUATION OF THE APPROACH

Because of severe time constraints, information needed for this study had to be collected quickly. An early obstacle was a paucity of documented information which might link impacts on the ecosystem and nontimber benefits to possible changes in the Forest Service's harvesting policy. We overcame this obstacle by consulting resource specialists who were asked to identify impacts and then to estimate both the magnitudes of impacts and the likely responses of various interest groups. Tables 3 and 4 show the results.

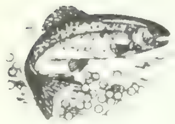
The critical part of the study involved developing criteria against which impacts could be compared. Impacts on the ecosystem were formulated in terms of goals, e.g., "maintain or enhance...," that society has expressed through various laws and regulations as desirable environmental conditions. Criteria for nontimber benefits were formulated in terms of use levels. For these criteria, the concept of threshold of concern was used to identify changes in use levels that were socially significant.

A major drawback in our attempts to assess the magnitude of impacts was that the timber resource information used in generating timber harvest schedules was too broadly defined to be useful in identifying harvests that might occur in specific areas that are sensitive from an environmental or nontimber benefit point of view. Because of this, resource specialists could only estimate the magnitude of impacts for the Forest as a whole, which resulted in very imprecise statements; i.e., "minor" and "major" impacts.

Another major drawback was uncertainty concerning what the Forest Service would do with increased investment funds. What proportion of these funds would be used to mitigate adverse impacts of increase timber production? For purposes of evaluation, we assumed that increased funding for protection of nontimber benefits would be proportional to increases in funds for intensified management. Many of the resource specialists commented that if funding could be increase more than proportionally, many of the major adverse impacts could be reduced or eliminated.

In retrospect, we now feel that resource managers should have been included on the panels to help evaluate the importance of impacts. Although the resource specialists did an adequate job in determining major and minor impacts, a decisionmaker's perspective would have helped us to better understand how impacts are perceived and acted on by decisionmakers.

In conclusions, although the study had its problems and its results are imprecise concerning the connections between proposed actions and their resulting impacts, we believe the results strongly indicate the problems and trends that can be expected if harvest schedules or investment levels are changed. Moreover, the approach used in this study, though hurried and with little data, did result in highlighting problem areas which managers can use to better assess the consequences of alternative actions.



APPENDIX

Panel Participants

Panels of U.S. Forest Service and State resource specialists included the following:

Watershed Panel

Bob Meurisse, Leader, Soils Group, R-6
Gerry Swank, Leader, Watershed Management Group, R-6
Art Tiedemann, Project Leader, Wenatchee Lab
Dave Helvey, PNW, Wenatchee Lab
Glen Klock, PNW, Wenatchee Lab
Dennis Harr, PNW, Corvallis Lab

Range Panel

Fred Hall, Ecologist, R-6
Rick Ross, Land Use Planning Team, Mt. Hood National Forest
Jon Skovlin, Range Scientist, PNW, La Grande Lab
Lou Spink, Regional Range Vegetation Improvement Specialist, R-6
Ray Zolanardo, Umpqua National Forest

Fish Management Panel

Gene Deschamps, Washington State Department of Fisheries
Fred Everest, Siskiyou National Forest
Bill Meehan, Fisheries Biologist, PNW, Corvallis Lab
Monty Montgomery, Oregon State Department of Fish and Wildlife

Wildlife Management Panel

Bernie Carter, Ochoco National Forest
Garry Garrison, Washington State Department of Game
Kirk Horn, Wildlife Biologist, Mt. Hood National Forest
Carlos Pinto, Okanogan National Forest
Gene Silovsky, Siuslaw National Forest
Jack Thomas, Project Leader, PNW, La Grande Lab

Recreation Panel

Don Warman, Recreation Management, R-6
Roger Stamie, Umpqua National Forest
Phil Gillman, Ochoco National Forest
John Hendee, Project Leader, PNW, Seattle

METRIC EQUIVALENTS

1,000 acres = 404.69 hectares
1 mile = 1 609.344 meters

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GENERAL TECHNICAL REPORT PNW-82
MARCH 1979

Selection, Management and Utilization of

BIOSPHERE RESERVES

Pacific Northwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

ABSTRACT

This publication is directed to the analysis of the selection, management, and utilization of Biosphere Reserves as viewed by scientists from the United States and the Union of Soviet Socialist Republics. Soviet papers focus on types of research and monitoring programs that should be developed on Biosphere Reserves, with emphasis on their use in pollutant monitoring. The nature of the U.S. Biosphere Reserves and their current and potential value for research, education, and biological preservation is considered in the U.S. papers. An additional paper provides an international perspective on U.S. and Soviet collaboration in the field of Biosphere Reserves. Characteristics of Soviet Biosphere Reserves are described in an appendix.

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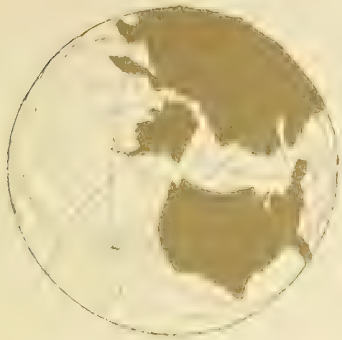

Selection, Management and Utilization of BIOSPHERE RESERVES

Proceedings of the
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PREFACE

In 1974 a project on Biosphere Reserves was established between the United States (U.S.) and Union of Soviet Socialist Republics (U.S.S.R.) under the bilateral agreement on Cooperation in the Field of Environmental Protection. The project was a recognition of the common interest in establishing and using Biosphere Reserves as sites for major ecological research and environmental monitoring programs, as well as for preservation of natural ecosystems and gene pools.

A bilateral meeting of scientists and administrators associated with Biosphere Reserves was held to initiate an exchange of information and viewpoints. This symposium on Biosphere Reserves was hosted by the U.S.S.R. from May 5 to 17, 1976 in Moscow and in several European and central Asian republics. Topics included the selection, scientific utilization, and management of Biosphere Reserves. A report on characteristics of U.S. Biosphere Reserves was reviewed and visits were made to several proposed (and subsequently established) Biosphere Reserves in the U.S.S.R.

This volume is the English-language proceedings of that symposium. A Russian-language version of the proceedings was published in 1977.[1] The contents of both volumes are as identical as we could make them except that an appendix, outlining characteristics of Biosphere Reserves in the U.S.S.R., has been added; these Biosphere Reserves have been established since publication of the Russian-language proceedings.

The Soviet papers are edited from translations provided by the U.S.S.R. with refinement and incorporation of additional material from the Russian-language proceedings. Soviet scientists had limited opportunity to check the final English translations so errors in content are our responsibility as technical editors; for definitive versions of the Soviet papers we refer readers to the Russian-language proceedings. Similarly, literature citations for the Soviet papers were extremely difficult to check; so, contrary to normal procedure, citations for the Soviet papers are generally translated as printed in the Russian-language proceedings and referred to as "References."

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[1] Biosphere Reserves, Works of the First Soviet-American Symposium, Publishing House for Hydrometeorology, Leningrad, U.S.S.R.

The reader will note some general differences in orientation between the U.S. and Soviet papers. The U.S. philosophy has been to identify and establish a large series of Biosphere Reserves which will vary widely in the level of research and environmental monitoring programs. These are viewed as outstanding sites where various independent programs can be located. The potential is limited for a comprehensive program involving essentially identical efforts at all or even a majority of U.S. Biosphere Reserves. Research and monitoring programs are, in effect, to be developed by drawing in and coordinating projects with independent but compatible objectives and funded from various sources. The U.S. papers reflect the constraints of this approach.

The Soviets, on the other hand, view their Biosphere Reserves as sites where comprehensive research and environmental monitoring programs will be carried out. It is their intention that programs at all Biosphere Reserves be comparable in content and intensity and Soviet Biosphere Reserves have been selected with that in mind. For this reason, the Soviet papers strongly address the general research and monitoring activities that can and should be carried out on Biosphere Reserves; they are, in effect, proposing the content of comprehensive, coordinated efforts in their whole set of Biosphere Reserves. This is also the basis for the constraint in designation of Biosphere Reserves; i.e., to establish as Biosphere Reserves only the number and types of sites where major programs are possible. With the intense interest in Biosphere Reserves demonstrated by the U.S.S.R. Academy of Sciences and State Committee for Hydrometeorology and Control of the Natural Environment, both the resources and the will are available to carry out the Soviet design.

Activities have progressed under the bilateral program during the 2-1/2 years that have elapsed since the symposium. Most significant is the recent agreement on a common program for environmental pollutant monitoring program for Soviet and U.S. Biosphere Reserves. This program will be implemented on at least one Biosphere Reserve in each country during 1979 and will provide the basis for future expansion of coordinated data collection and exchange in this and other topics.

JERRY F. FRANKLIN
STANLEY L. KRUGMAN
March 1979

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The Conceptual Basis for Selection of U.S. Biosphere Reserves and Features of Established Areas

by

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INTRODUCTION

A bilateral program on Biosphere Reserves must begin with a mutual understanding of the philosophy which is guiding the selection, scientific utilization, preservation, and management of such areas. Such an understanding also requires that scientists in the countries involved know the physical and biological features and research programs on areas designated as Biosphere Reserves. In this way the basis is laid for identifying areas where conservation management programs or research and monitoring programs or both are of mutual interest and where collaboration would be beneficial.

Mutual exposure to the Biosphere Reserve programs in the U.S.S.R. and U.S.A. is a primary purpose of this symposium. I will attempt in this paper to: (1) outline the philosophy of the U.S. Committee for Man and the Biosphere (MAB) Project 8 followed in selecting areas as Biosphere Reserves; and (2) sketch the important features of the 28 U.S. areas that have been designated by UNESCO as Biosphere Reserves.

SELECTION OF U.S. BIOSPHERE RESERVES

Let us begin with an idealized Biosphere Reserve as outlined in the UNESCO documents. What would be among its most important attributes leaving aside for the moment the unique, domesticated, or severely impacted categories of Biosphere Reserves?

1. The area would be a large and diverse segment of the biosphere, in a natural or near-natural condition, which is highly representative of the biological and physical features found in a Biotic Province;

2. The area would have the conservation of biotic diversity, scientific research, and education as its primary land use directives--these directives established and enforced by the Sovereign State in which it is located;

3. The area would be of sufficient size to be viable as a conservation unit and to allow for large-scale replicated experiments without damage to the conservation function; and,

4. The area would have a large established research and monitoring program to provide a good data base and staff for future research and for guidance in the management of the property.

This idealized Biosphere Reserve would be a rare situation in any country. We quickly find that most potential areas lack one or more essential feature, whether it be protective status, level of existing research programs, or overall size.

When we looked at the guidelines for Biosphere Reserves in the United States, two constraints were obvious. First, most public lands are already legally committed to various purposes so that the possibility of creating large new scientific reserves is remote, outside of Alaska. Hence, we needed to consider what could be done using existing reserves dedicated to recreation, conservation, and science.

Second, U.S. participants in MAB Project 8, felt it important to emphasize the research and monitoring aspects of the Biosphere Reserve program. This is not necessarily the worldwide emphasis of MAB Project 8 since a major goal for the Biosphere Reserve program is to stimulate conservation efforts in areas where they presently lag. Where there are already numerous effective conservation programs, as in the U.S.A. and U.S.S.R., research and monitoring is an appropriate distinguishing element for the Biosphere Reserves program. Since the prospect of quickly generating large new research and monitoring efforts was and is limited, we needed to consider utilizing present field "laboratories" which are outstanding sites or centers of excellence for ecological research.

Thus, with these constraints in mind, the U.S. MAB Committee for Project 8 began its examination of potential Biosphere Reserve sites. Initially, we decided to search only for the least disturbed representatives of the major Biotic Provinces as outlined by the International Union for the Conservation of Nature (1974; Udvardy 1975); a few provinces were subdivided to deal with major variants. Our objective was a Biosphere Reserve within each Province or subdivision which would provide an outstanding representation of the biological and physical features and a well established research program.

Two categories of land owned by the U.S. Government are the obvious candidates for Biosphere Reserve status. First, there are the National Parks and Monuments, administered by the National Park Service (U.S. Department of the Interior) and the Wilderness Areas, administered by a variety of agencies under common Congressional guidelines. The National Parks clearly have preservation of the landscape and biota as one of two primary objectives, the other being provision for citizen use and enjoyment. This dichotomy in objectives, roughly describable as preserving nature while simultaneously providing for human recreation, is almost as apparent in the direction for Wilderness management. In either case, the lands are not preserved primarily as scientific "laboratories" although this use is recognized. Preservation of physical and biological features is a primary objective, however, and these tracts represent some of the finest examples of large natural landscapes and, in some Biotic Provinces, the only

significant surviving examples. Research and monitoring programs in the National Parks and in Wilderness Areas, however, have generally been poorly supported. Research has been further limited by the incompatability of many manipulative-type research projects with the primary land-use directives--natural preservation and human enjoyment of the areas.

The second category of relevant areas is the series of reservations which have been established by various agencies as locations for field-oriented research projects and small-scale (pilot) applications of research findings. Examples are the Experimental Forests and Ranges of the USDA Forest Service, some Experiment Stations of the Agricultural Research Service (U.S. Department of Agriculture), and several land reservations under the jurisdiction of the Energy Resources and Development Agency (ERDA). These are sites where scientific use is a primary land-use directive and they are typically under managerial control of research organizations. They are generally of moderate size (e.g., 1 000 to 50 000 ha) and most often are specifically selected as broadly representative of Biotic Provinces or major plant formations. Active research programs have been going on at many of these sites for several decades. A large proportion of the applied, agency-sponsored field research has been and still is centered on these sites. The selection of several of these reservations as intensive study sites by the university scientists who organized U.S.—International Biological Program (IBP) research projects attests to their outstanding character and has resulted in greatly expanded efforts in basic ecological research at these installations. Dr. Risser's paper in this symposium provides further evidence for the continuing and expanding collaboration of basic academic and applied agency scientists on these reservations.

These scientifically-dedicated reserves, which are sometimes referred to as Experimental Ecological Reserves (EER's), are, however, generally not the complete or "ideal" Biosphere Reserve either. Their size, while sufficient for replicated, large-scale field experiments and appropriate control areas, is typically too small to allow for the very large, strictly preserved tracts of the sort necessary for protecting a sample of the organic diversity within a Biotic Province. Conversely, application of a strict "hands-off" policy would seriously limit their usefulness as experimental sites.

The U.S. MAB Committee for Project 8 decided that the best solution to this dilemma was a matching of selected large, natural reserves with nearby research-rich, experimentally oriented reservations. Together a pair of areas would fulfill the functions or concept of a Biosphere Reserve in each Biotic Province.

This, then, was the philosophical basis on which the initial selections of Biosphere Reserve candidate areas were made (fig. 1), (table 1). All of the sites selected share the common feature of being an outstanding example of the physical and biological features of the Biotic Province in which they are located. In general, where there are pairs of areas, one is the best of the natural or conservation-oriented reserves within the Province, while the other represents the outstanding center for field research and experimentation

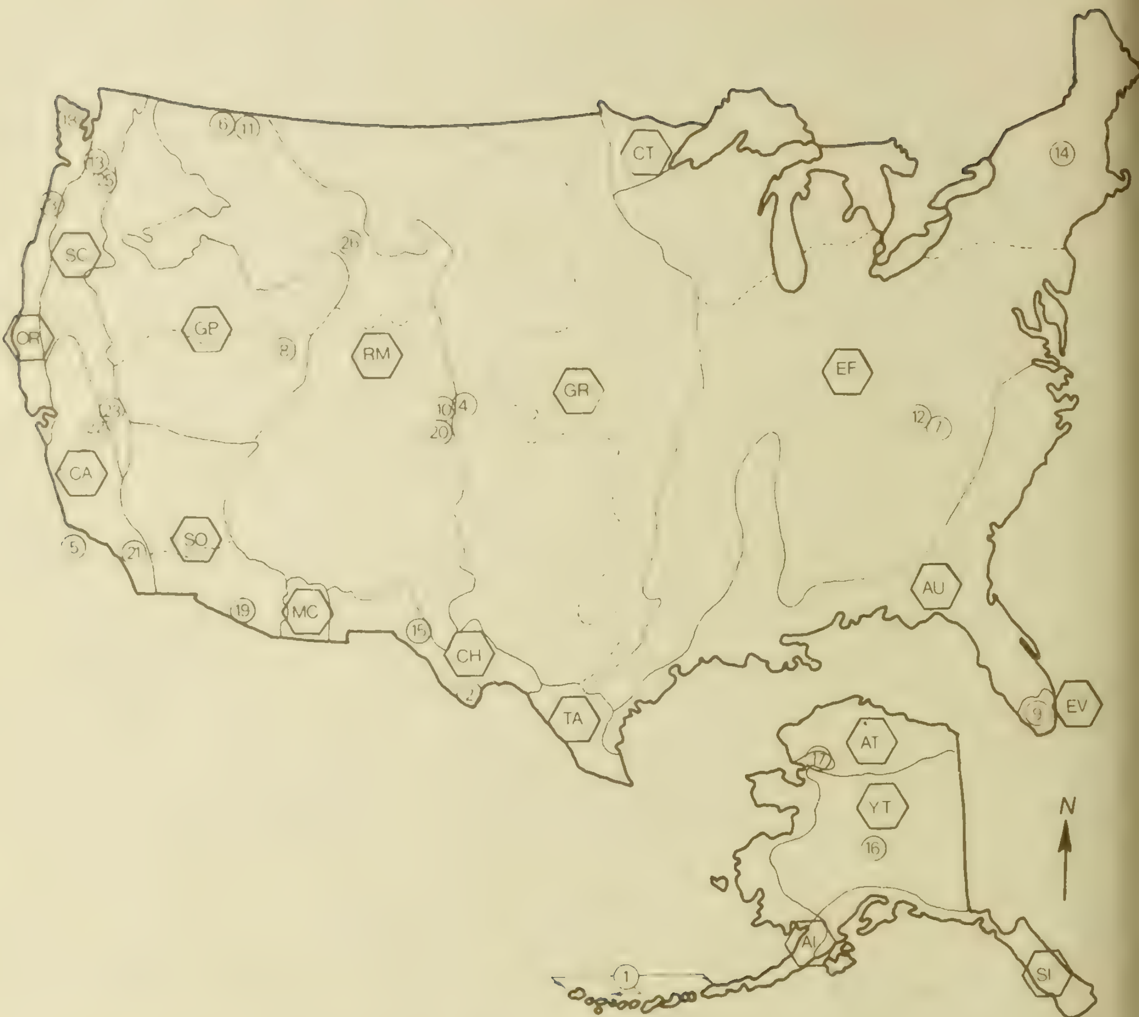

Figure 1.—Location of established biosphere reserves and biotic provinces in the continental United States (including Alaska); province subdivisions are indicated by dotted lines. Alphabetic designations refer to biotic provinces: *AI*, Aleutian Islands; *AT*, Alaskan Tundra; *AU*, Austroriparian; *CA*, Californian; *CH*, Chihuahuan; *CT*, Canadian Taiga; *EF*, Eastern Forest; *EV*, Everglades; *GB*, Great Basin; *GR*, Grasslands; *MC*, Madrean-Cordilleran; *OR*, Oregonian; *RM*, Rocky Mountains; *SC*, Sierra-Cascade; *SI*, Sitkan; *SO*, Sonoran; *TA*, Tamaulipan; *YT*, Yukon Tundra. Numbered areas refer to biosphere reserves: 1, Aleutian Islands National Wildlife Refuge; 2, Big Bend National Park; 3, Cascade Head Experimental Forest; 4, Central Plains Experiment Station; 5, Channel Islands National Monument; 6, Coram Experimental Forest; 7, Coweeta Experimental Forest; 8, Desert Experimental Range; 9, Everglades National Park; 10, Fraser Experimental Forest; 11, Glacier National Park; 12, Great Smoky Mountains National Park; 13, H. J. Andrews Experimental Forest; 14, Hubbard Brook Experimental Forest; 15, Jornada Experimental Range; 16, Mount McKinley National Park; 17, Noatak National Arctic Range; 18, Olympic National Park; 19, Organ Pipe Cactus National Monument; 20, Rocky Mountain National Park; 21, San Dimas Experimental Forest; 22, San Joaquin Experimental Range; 23, Sequoia-Kings Canyon National Parks; 24, Stanislaus Experimental Forest; 25, Three Sisters Wilderness; 26, Yellowstone National Park.

Table 1--Distribution by biotic provinces and characteristics of established Biosphere Reserves in the United States and its territories

Biotic province or subdivision[1]	Name and location or area	Outstanding features	Size (ha)	Administering agency	Orientation[2]
Alaska tundra	Noatak National Arctic Range, Alaska	Major arctic river basin (tundra ecosystems)	3 000 000	Department of the Interior, Bureau of Land Management	C
Aleutian Islands	Aleutian Island National Wildlife Refuge, Alaska	Includes essentially all the Aleutian Island chain	1 100 000	Department of the Interior, Fish and Wildlife Service	CE
Austroriparian[3]					
Californian	Channel Islands National Monument, California	Two islands (453 ha) and adjacent ocean; abundance of endemic biota and marine fauna	7 440	Department of the Interior, National Park Service	
	San Dimas Experimental Forest, California	Typical chaparral ecosystem; history of ecological and watershed research	6 947	Department of Agriculture Forest Service	I
	San Joaquin Experimental Range, California	California Central Valley annual grassland and oak savanna; history of ecological and range management research	1 861	Department of Agriculture, Forest Service	I
Chihuahuan	Big Bend National Park, Texas	Representative desert mountain and lowland ecosystems	286 600	Department of the Interior, National Park Service	C
	Jornada Experimental Range, New Mexico	Typical desert grasslands; history of ecological and range management research	77 000	Department of Agriculture, Agricultural Research Service	I
Eastern forest[3] (south)	Coweeta Experimental Forest, North Carolina	Typical southern Appalachian mixed hardwood forest; history of watershed and ecological research	2 300	Department of Agriculture, Forest Service	I
	Great Smoky Mountains National Park, Tennessee and North Carolina	Appalachian mountainscape with rich biotic diversity including hardwood and spruce-fir forests; history of ecological and biogeographical research	207 500	Department of Interior, National Park Service	[illegible]
Eastern forest (northeast)	Hubbard Brook Experimental Forest, New Hampshire	Typical northern Appalachian mountain drainage of mixed hardwoods and spruce; history of ecosystem and watershed research	3 075	Department of Agriculture, Forest Service	
Eastern forest[4] (northcentral)					
Everglades	Everglades National Park, Florida	Subtropical forest, mangrove, swamp, and marshland and near-shore marine ecosystems; rich biota; substantial ecological research including experimental manipulations	566 800	Department of the Interior, National Park Service.	CE
Grasslands (short-grass)	Central Plains Experiment Station, Colorado	Typical short-grass prairie ecosystems; history of ecological and range management research	6 280	Department of Agriculture, Agricultural Research Service	I
Grasslands (true prairie)					
Great Basin[3] (north)					
Great Basin (south)	Desert Experimental Range, Utah	Typical salt desert shrub (salt bush-greasewood) and juniper-pinyon pine ecosystems; history of ecological and range management research	22 513	Department of Agriculture, Forest Service	I
Greater Antillean	Luquillo Experimental Forest, Puerto Rico	Tropical rain forest, montane thicket, palm and dwarf forest ecosystems; rich biota; history of ecological and silvicultural research	11 300	Department of Agriculture, Forest Service	I
Hawaiian[4]					
Lesser Antillean	Virgin Islands National Park, Virgin Islands	Tropical ecosystems including near-shore marine areas	[illegible]	Department of the Interior, National Park Service	C
Micronesian[4]					

(See following page)

Table 1--Distribution by biotic provinces and characteristics of established Biosphere Reserves in the United States and its territories--Continued

Biotic province or subdivision[1/]	Name and location of area	Outstanding features	Size (ha)	Administering agency	Orientation[2/]
Oregonian	Cascade Head Experimental Forest and Scenic Research Area, Oregon	Coastal Sitka-spruce western hemlock forests and estuary, history of ecological and silvicultural research	7 051	Department of Agriculture, Forest Service	E
	Olympic National Park Washington	Coastal mountain system with dense coniferous forest, coastal and alpine ecosystems, abundant glaciers and large elk herds	362 850	Department of the Interior, National Park Service	C
Rocky Mountain (north)	Coram Experimental Forest, Montana	Typical montane mixed conifer forests of Douglas-fir, western larch, and lodgepole pine, history of ecological and silvicultural research	2 981	Department of Agriculture, Forest Service	E
	Glacier National Park, Montana	Broad range of typical mountain landscapes and ecosystems from prairie margin to alpine	410 000	Department of the Interior, National Park Service	C
	Yellowstone National Park, Wyoming, Idaho, and Montana	Unique area with abundant thermal phenomena and larger mammals, history of ecological research	900 000	Department of the Interior, National Park Service	C
Rocky Mountain (south)	Fraser Experimental Forest, Colorado	Subalpine forests of subalpine fir, Engelmann spruce, and lodgepole pine and alpine tundra, history of ecological and watershed research	9 300	Department of Agriculture Forest Service	E
	Rocky Mountain National Park, Colorado	Typical montane and subalpine forest ecosystems and alpine tundra	106 160	Department of the Interior, National Park Service	C
Sierra-Cascade (north)	H. J. Andrews Experimental Forest, Oregon	Dense coniferous forest ecosystems of Douglas-fir, western hemlock, cedars, and true firs; history of ecosystem and watershed research	6 050	Department of Agriculture, Forest Service	E
	Three Sisters Wilderness, Oregon	Dense montane and subalpine forests of Douglas-fir, hemlocks, and true firs, alpine ecosystems, and recent volcanic formations	80 900	Department of Agriculture, Forest Service	C
Sierra-Cascade (south)	Sequoia-Kings Canyon National Parks, California	Representative Sierran mixed conifer forests (sugar pine, incense cedar, true firs); subalpine and alpine ecosystems	342 754	Department of the Interior, National Park Service	C
	Stanislaus Experimental Forest, California	Representative Sierran mixed-conifer forests; history of ecological and silvicultural research	683	Department of Agriculture, Forest Service	E
Sitkan[4/]					
Sonoran (typical)	Organ Pipe Cactus National Monument, Arizona	Desert ecosystems including rich diversity of cacti	134 000	Department of the Interior, National Park Service	C
Sonoran (Mohave)[4/]					
Yukon Taiga	Mt. McKinley National Park, Alaska	Representative tundra and taiga ecosystems including large ungulate and predator components	784 900	Department of the Interior, National Park Service	C

1/ Biotic provinces are as defined in "A Classification of the Biogeographical Provinces of the World" (Miklos D. F. Udvardy, International Union for Conservation of Nature Occasional Paper 18, 48 p., 1975) with additional subdivisions by U.S. MAB Committee for Project 8.

2/ "Orientation" refers to whether the area is oriented primarily toward conservation (C) or experimental research (E).

3/ The Savannah River Plant, Oak Ridge (TN), and Arid Lands Ecology (WA) Reservations of the Energy Research and Development Administration (ERDA) have been proposed for sites in the Austroriparian, Eastern Forest (south) and Great Basin (north) Biotic Provinces, respectively. However, ERDA has, thus far, not designated any portions of these sites as Biosphere Reserves because of concerns over agency prerogatives.

4/ Good candidates for Biosphere Reserves have been identified, but a final selection has not been made.

in that Province. It is planned that the paired conservation and experimentally oriented Biosphere Reserve will develop collaborative programs to fulfill the conservation, research, and educational goals of the MAB Program. Examples of appropriate collaborations and linkages are apparent in other symposium papers by Evison and by Johnson, Olson, and Reichle.

There are some deviations from the philosophical framework I outlined above. First, the U.S. has obviously not nominated candidate Biosphere Reserves within all of the Biotic Provinces. In some Provinces, selection of the superlative site will require careful, comparative evaluation of alternative tracts. In other Provinces, candidates have been selected but the concurrence of the responsible agency in nominating the site has not been forthcoming. In a few Provinces, a single area can or of necessity will have to fulfill all functions of a Biosphere Reserve.

Alaska presents the United States with a special opportunity since here it will be possible to create new reserves of sufficient size and management flexibility to fulfill all Biosphere Reserve functions. Selection of candidates is proceeding slowly, however, due to uncertainties as to the ultimate allocation of lands among various ownerships and Federal agencies. There is also the added difficulty of initiating major new research programs in these remote and poorly known regions. Nevertheless, Alaska does provide outstanding opportunities for establishing Biosphere Reserves in the future.

CHARACTERISTICS OF U.S. BIOSPHERE RESERVES

The remainder of my paper is devoted to summaries of the important natural features and research programs on Biosphere Reserves in the United States. It is intended to introduce the audience to the sites thereby helping Soviet and other scientists to identify U.S. Biosphere Reserves which are of special interest. The U.S. MAB Committee for Project 8 has identified three additional sites with outstanding potential as Biosphere Reserves and requested their designation but the responsible agency has not yet agreed to their nomination; these are the Savannah River and Oak Ridge Reservations and Arid Lands Ecology Reserve of the Energy Resources and Development Agency.

Aleutian Islands National Wildlife Refuge

This 1 100 000-ha reserve includes all but seven of the islands within the Aleutian Island chain (lat. 52° 40'N long. 177°N 30'W). There are a total of nearly 70 named islands. This area is administered by the Fish and Wildlife Service (USDI). The climate is cool, foggy, and rainy; and the topography is mostly mountainous with elevations ranging up to 2 700 m. There are many lakes and streams and thousands of kilometers of rugged coastline. The vegetation is primarily tundra with *Salix* and *Alnus* shrub communities. Offshore waters support extensive kelp beds.

The fauna is rich and includes both Asiatic and North American elements. The sea otter (*Enhydra lutris*) now numbers nearly 20,000. The northern sea lion (*Eumetopias jubata*) is common. Unimak Island has a population of Alaskan brown bear, (*Ursus arctos*), over 1,000 caribou (*Rangifer arcticus*), and many wolves (*Canis lupis*) and wolverines (*Gulo luscus*). More than 2,000 wild reindeer (*Rangifer tarandus*) live on Atka Island. Small mammals, except for the tundra vole (*Clethrionomys rutilus*) and Norway rat (*Rattus norvegicus*) (introduced), are rare west of Unimak Island. Streams are heavily used by spawning salmon.

Colonial sea birds are the most conspicuous faunal element. The vast rookeries include fulmars, (*Fulmarus glacialis*), two species of petrels (*Oceanodroma* spp.), three species of cormorants (*Phalacrocorax* spp.), black-legged kittiwakes (*Rissa tridactyla*), glaucous-winged gulls (*Larus glaucescens*), guillemots (*Cepphus columba*), murres (*Uria* spp.), murrelets (*Synthliboramphus antiquus*), six species of auklets (*Aethia* spp., *Cerorhinca* sp., *Cyclorrhynchus* sp., *Ptychoramphus* sp.), two species of puffins (*Fratercula corniculata* and *Lunda cirrhata* and three species of loon (*Gavia* spp.). Large numbers of waterfowl winter in and among the islands and others nest there during the summer. The Aleutian Canadian goose (*Branta canadensis leucopareia*) exists only on Buldir Island. Bald eagles (*Haliaeetus leucocephalus*) and falcons (*Falco* spp.) are common. A number of Asiatic birds also have been found. Substantial faunal and anthropologic research has been conducted on the islands with Amchitka Island being the most comprehensively studied.

Big Bend National Park

This 286 600 ha reserve was established in 1944 along the Rio Grande River in southwestern Texas (lat. 29° 15'N long. 103° 15'W). It is administered by the National Park Service. There are many deep canyons and the entire Chisos Mountain range is in this rugged region of limestone and igneous extrusive rocks. Elevations range from 540 to 2 350 m. Average rainfall in the lowlands is 33.5 cm of which most occurs from May through October.

The area is an outstanding example of the Chihuahuan Desert Biotic Province. Major ecosystem types include shrub, succulent grass, desert, chaparral, evergreen and evergreen-deciduous woodland, and river flood-plain-arroyo (Wauer 1973, Whitson 1974). A lower desert formation is dominated by *Larrea tridentata*, *Flourensia cernua* and locally *Prosopis glandulosa* and *Atriplex canescens*. This formation grades into mid-elevation desert formation dominated by succulents or semi-succulents (commonly *Agave lecheguilla*, *Opuntia engelmannii*, *Hechtia scariosa*, *Euphorbia antisyphilitica*, *Jatropha dioica*, and *Dasylirion leiophyllum*) with local occurrences of shrubs (e.g., *Rhus virens*, *Acacia constricta*, *Ephedra* sp., and *Fouquieria splendens*) and/or grasses (e.g., *Bouteloua breviseta* and *B. eriopoda*). Chapparral is found at higher elevations and is characterized by a shrub and tree canopy usually less than 1.5 m tall; *Quercus* spp., *Cercocarpus montanus*, *Viguiera stenoloba*, and *Rhus aromatica* are characteristic. Evergreen and mixed evergreen-deciduous woodlands are generally found above 1 500 m and consist of widely spaced trees up to 8 m tall.

Typical species are *Quercus grisea*, *Q. emoryi*, *Q. gravesii*, *Juniperus pinchotii*, and *J. deppeana*.

Distinctive vertebrates include the javelina (*Pecari angulatus*), yellow-throated packrat (*Sigmodon ochrognathus*), Colima warbler (*Vermivora crissalis*), roadrunner (*Geococcyx californianus*), mule deer (*Odocoileus hemionus*) and mountain lion (*Felis concolor*).

Cascade Head Experimental Forest and Scenic Research Area

The Cascade Head Experimental Forest was established in 1934. A part of this experimental reserve was incorporated within the unique Cascade Head Scenic Research Area established by Congress in 1974. The two areas together provide a 7 050-ha Biosphere Reserve on the Oregon coast (lat. 45° 02'N, long. 123° 59' W). The site is administered by the U.S. Forest Service. The Experimental Forest occupies the crest and slopes of a prominent basaltic headland which juts into the Pacific Ocean. Topography is generally rugged with elevations ranging from sea level to 525 m. The area has a maritime climate with cool summers and wet, mild winters (annual precipitation 248 cm); an important climatic feature is the fog which covers the headland many summer afternoons.

Dense forests of *Picea sitchensis* and *Tsuga heterophylla* are dominant biological features. Most of these forests reproduced following wildfires in the 1840's. These are extremely productive with standing crops (live biomass) in excess of 900 tons per ha in some mature forests and annual rates of production in excess of 30 tons per ha in some young stands. Some areas disturbed more recently are occupied by stands in which *Alnus rubra* is a major or sole dominant. Natural meadows occur on some exposed portions of the headland. Sea cliffs and rocky beaches are common providing habitat for numerous sea birds and haul-out areas for marine mammals such as northern sea lions.

The Experimental Forest has been a primary area for studies of the ecology and silviculture of coastal *Picea-Tsuga* and *Alnus rubra* forests. Growth and yield of natural stands, harvest methods, and regeneration of trees, and nutrient cycling, including the effects of *Alnus* on the nitrogen regime, have been major research subjects.

The Scenic Research Area adds the entire estuary of a small river although much of the estuary and adjacent slopes have been modified and are occupied by humans. Major objectives in this part of the Biosphere Reserve are restoration of the estuary and provision for human occupancy of adjacent slopes in manners consistent with maintenance of natural and scenic properties. The research program is focused largely on solution of management problems such as development of techniques for restoration of salt marsh areas which have been diked pasturelands.

Channel Islands National Monument

Channel Islands National Monument consists of two small islands (7 440-ha) off the southern California coast (lat. 34° 01'N, long. 119° 23'W) and has been administered by the National Park Service since it was established in 1938. Selection as a Biosphere Reserve was based on the recognition of a California Islands Biogeographic Province in the earlier International Union for the Conservation of Nature (IUCN 1974) classification. Anacapa Island is 15 km from the mainland and is a rugged rocky area about 8 km long and less than 1 km wide. Santa Barbara Island is over 60 km at sea and is also rugged; rocky bays and sandy beaches are present as well as vertical cliffs and gentler uplands. Most of the 35 cm of rainfall occurs in the winter; summers are warm and dry.

The area has an outstanding diversity of biota including many endemic species, which is the major reason it was established. Sea birds, many of which nest on the islands, and marine mammals, such as California sea lions (*Zalophus californianus*) and sea elephants (*Mirounga angustirostris*), are important elements. Floristic elements are also distinctive, one of the most conspicuous elements being the giant coreopsis (*Coreopsis gigantea*) which occasionally attains a height of 2-1/2 m. Research is focused largely on population and ecological studies of several faunistic groups including marine mammals and sea birds.

Central Plains Experimental Range

This 6 285-ha reserve is located in northeastern Colorado and is administered by the Agricultural Research Service (U.S. Department o Agriculture). The site is located on the Colorado Piedmont, (lat. 40° 49'N, and long. 104° 46'W), which is a large erosional depression carved from a high plains surface. Topography is gentle and rolling. The site is located immediately in the lee of the Rocky Mountains and, therefore, has a semi-arid continental climate which could be classed as a cool-steppe climate. Annual precipitation is 31 cm with about 50 percent occurring from May through Augus from thunderstorm activity. Winter climate is dominated by continental polar air masses. The lowest maximum monthly mean temperatur is 7°C in both January and December.

Vegetation is generally described as native short grass prairie, and it is dominated by *Bouteloua gracilis* and *Buchloë dactyloides* supplemented by *Carex eleocharis* and *C. filifolia*. Several midgrasses such as *Agropyron smithi*, *Stipa comata*, and *S. viridula* grow in association with the short grasses but seldom obtain sufficient densities to dominate. Leading browse species are *Artemisia frigida*, *Atriplex canescens*, and *Eurotia lanata*. Other common shrubs are *Chrysothamnus nauseosus*, *Gutierrezia sarothrae*, and *Artemisia tridentata*. *Opuntia polyacantha* is widely distributed. Common vertebrates include pronghorn antelope (*Antilocapra americana*), jackrabbit (*Lepus* spp.), thirteen-lined ground squirrel, (*Spermophilus tridecemlineatus*), northern grasshopper mouse (*Onychomys leucogaster*), and Ord kangaroo rat (*Dipodomys ordii*). The most common birds are

lark buntings (*Calamopsiza melanocorys*) and horned larks (*Eremophila alpestris*).

Since it was established in 1939, the Central Plains Experimental Range has been extensively used for research on range management and structure and function of short grass prairie ecosystems. Much of the early work had to do with range management such as studies of stocking rates, grazing intensities, plant phenology, plant ecology, timing of summer grazing, fertilization, and range improvement. In more recent years, the scope of studies has increased, particularly since it was selected as the intensive site for the Grasslands Biome Project (U.S.—IBP) in 1967. A large team from this project has analyzed the fundamental structural and functional characteristics including structural features of trophic compartments, and their variation in time and space and under stress. There has been a broad array of studies relating to ecosystem processes such as primary and secondary production, energy flow, nutrient cycling, and abiotic and biotic controls on material and energy cycles. This information is being synthesized using mathematical models as well as classical techniques. It would be fair to describe the Pawnee Site, a small section of the Central Plains Experimental Range, as probably the best understood and described segment of North American grassland.

Coram Experimental Forest

This 2 984-ha area is located in the northern Rocky Mountain region of western Montana (lat. 48° 25'N, long. 114° 0'W) and is administered by the U.S. Forest Service. The mountainous tract consists generally of steep topography with some glacier till plains and terraces; it was heavily glaciated in the past. Bedrock consists of argillites, quartzites, and impure limestone.

The area is considered to be highly representative of vast acreages of northern Rocky Mountain mixed conifer forests. The primary type consists of *Pseudotsuga menziesii-Larix occidentalis*. With an elevational range of 1 022 to 1 952 m, there is a considerable range in environments and communities, however, from climax *Pseudotsuga* forests at lowest elevations (25 percent of the area) through mesic midslope forests (64 percent) to subalpine forest ecosystems dominated by *Abies lasiocarpa* and *Picea engelmanii* (11 percent). In addition to the *Larix* and *Pseudotsuga*, the midslope forests also contain substantial numbers of *Pinus monticola*, *Thuja plicata*, *Pinus contorta*, and *Tsuga heterophylla*. Most of the virgin forest is approximately 300 years old. The Coram Research Natural Area (338 ha) has been established as a major control area.

This Experimental Forest was established in 1933 and has been a site for intensive study of ecology and silviculture of forest ecosystems since 1946. Primary subjects which are currently being studied include entomology, pathology, phenology, hydrology, silviculture, and wildlife habitat.

Coweeta Experimental Forest and Hydrologic Laboratory

This 2 300-ha reserve is located in the southern Appalachian Mountains of southwestern North Carolina (lat. 35° 03'N, long. 83° 27'W) and is administered by the U.S. Forest Service. Topography is steep and rugged with elevations ranging from 675 to 1 575 m. Underlying rock is granite gneiss, mica gneiss, and mica-schist of pre-Cambrian origin. The soil mantle is relatively deep (averaging 90 to 150 cm) and porous. The climate is characterized by abundant precipitation (about 200 cm) and moderate temperatures (175 to 185 frost-free days).

Deciduous hardwood trees (there are nearly 60 species) are the dominant biologic feature. Generalized forest cover types are (1) northern hardwoods, (2) pine-hardwoods, (3) cove hardwoods, and (4) oak-hickory. The oak-hickory (*Quercus-Carya*) type is most extensive. In the coves (small moist basins) *Liriodendron tulipifer* and *Tsuga canadensis* are added to *Quercus* and *Carya* spp. Northern hardwood types occur at higher elevations and include *Acer saccharum*, *Betula alleghaniensis*, *Tsuga*, and *Tilia* with *Rhododendron* and *Kalmia* forming evergreen shrub understories. The *Pinus rigida-Quercus* forests are on dry ridges. The most significant disturbance to the natural condition has probably been the essential elimination of a forest dominant, *Castanea dentata*, by an introduced blight.

This reserve has a long and distinguished research history beginning with its establishment in 1934 as the major site for studies of the effects of forests and forestry practices on water yield and quality (Dils 1957). A major research technique has been the use of over 40 small (10- to 80-ha) unit watersheds as the basic units for experimental treatment and study. Major studies have included hydrologic consequences of mountain farming, woodland grazing, exploitive logging, forest cutting (with and without regrowth), removal of streamside vegetation, conversion from forest to grassland and from deciduous forest to *Pinus strobus* plantations, and normal forest practices. Movement of soil water has been studied using large size soil models. In recent years (partially in conjunction with its use as an intensive site in the Deciduous Forest Biome Project, U.S.—IBP), research on carbon and nutrient cycling has been intensified and is now a major element of the research program. Stream biology and forest succession are other important research areas. Coweeta has excellent on-site laboratory and data processing facilities.

Desert Experimental Range

This 22 513-ha tract is located in the Great Basin region of Uta (lat. 38° 40'N, long. 113° 45'W) and is administered by the U.S. Forest Service. Approximately 75 percent of the area is on alluvia slopes and valley bottoms with the remainder on mountainous rocklan. The elevations range is from 1 547 in the playa to 2 565 m in the rocky hill lands.

The Experimental Range is representative of salt desert shrub (*Atriplex-Sarcobatus*) and pinyon-juniper (*Pinus-Juniperus*) woodland ecosystems. Salt desert shrub and associated types cover 20 391 ha with *Atriplex confertifolia*, *Eurotia lanata*, *Chrysothamnus stenophyllus*, *Artemisia spinescens*, *Artemisia nova*, *Ephedra* spp., *Oryzopsis hymenoides*, and *Bouteloua gracilis* as dominant species. Charactersitic vertebrates are great basin kangaroo rat (*Dipodomys microps*), jackrabbits, whitetail antelope squirrel (*Ammospermophilus leucurus*), and deer mouse (*Peromyscus maniculatus*).

Research on grazing management and wildlife habitat has been underway since 1934. The entire property is fenced along with a 740-ha control area, twenty 50-ha experimental pastures, and 43 enclosures of which the majority are located within the pastures. Basic ecosystem-oriented research is being accelerated to match current levels in applied programs.

Everglades National Park

This subtropical reserve of 566 800 ha was established in 1947 on the southwestern tip of Florida and is administered by the U.S. National Park Service. It is an extremely rich biotic region dominated by wetland ecosystems of various types (George 1972). Porous limestone underlies this low, flat region. The complex ecosystems result from mixtures of tropical and temperate organisms, the effects of cycles of flood, drought and fire, and subtle variations in temperature and substrate conditions which represent the basic environmental mosaic.

Major ecosystem complexes include: Florida Bay and its associated sea grass beds, keys, mud banks, and coastal prairies; mangrove swamps in brackish water regions; tree-island glades, the fresh-water region famous for the "river of grass," including bay head, cypress head, willow head, hardwood hammock, sawgrass, and dwarf cypress communities; and the pine and hammock ridge ecosystems found on elevated "ridges" (perhaps 2 m above sea level). Fire is very important in the pine (*Pinus elliottii* var. *densa*) and hammock ridge ecosystems. Tree-island glade ecosystems are naturally dependent upon periodic floods and occasional fires (during drought years) to maintain their natural balance. Mangrove swamps can be differentiated into 3 main types: *Rhizophora mangle* (red mangrove), which is very water tolerant and grows well out into mud flats; *Avicennia nitida* (black-mangrove) which grows on areas exposed at low tides and has pneumatophores; and *Laguncularia racemosa* (white-mangrove) that grows farther back from the water. The mangrove-estuary complexes are extremely important and productive biological areas.

The biota is very rich with over 24 rare and endangered vertebrates including several wading birds, American crocodile (*Crocodylus acutus*), and green turtle (*Chelonia mydas*).

Research is usually linked with management programs and directed to: the role and use of fire; the control of exotic plants (*Casuarina*, *Melaleuca*, *Schinus*, and *Colubrina anaticus*); the rehabilitation of

abandoned farmlands; the effects of runoff levels on ecosystems; the fish populations and their distribution including fisheries in benethic habitats of Florida Bay (monitoring of water quality--salinity, temperature, dissolved O_2, pH, and turbidity)--is an integral part of these studies; and the ecology of several unique species including white ibis (*Eudocimus albus*), loggerhead turtle (*Caretta caretta*), bald eagle, American crocodile, wood stork (*Mycteria americana*), osprey (*Pandion haliaetus*) and roundtailed muskrat (*Ondatra zibethica*).

Fraser Experimental Forest

This 9 320-ha reserve is located in the central Rocky Mountain region in Colorado (lat. 39° 54'N, long. 105° 53'W) and is administered by the U.S. Forest Service. Steep, high mountain slopes with evidence of extensive glaciation are the most prominent topographic features; only about 10 percent of the area has slopes of 15 percent or less. Most of the soils are derived from gneisses and schists. Elevations range from 2 260 to 3 104 m.

The primary ecosystems present on this reserve are subalpine forests, alpine meadows, and some wet montane meadows. Virgin *Picea engelmannii-Abies lasiocarpa* forests cover 2 195 ha; *Pinus contorta* forests, 3 450 ha; *Populus tremuloides* stands, 125 ha; alpine tundra, 2 240 ha; and wet meadows and *Salix* communities 388 ha. There are also two small alpine lakes and 73.5 km of perennial streams. Typical fauna include elk, mule deer, white-tailed ptarmigan (*Lagopus leucurus*), and blue grouse (*Dendragapus obscurus*). This Experimental Forest was established in 1937. In addition to being highly representative of the forest and alpine ecosystems found in the central Rocky Mountains and the site of intensive research on watershed and timber management, this has been a primary area for the study of hydrological cycles in the Rocky Mountains.

Glacier National Park

This 410 000-ha tract was established in 1910 and is administered by the National Park Service. It is located in northwestern Montana (lat. 51° 45'N, long 117° 35'W) and was selected as being highly representative of the Rocky Mountain (northern subdivision) Biotic Province. Bedrock geology is dominated by metamorphic and igneous (extrusive and intrusive) materials in this uplifted mountain region. The area was heavily glaciated--molding most of the present landforms. Climate varies substantially over this rugged mountain reserve but it is wetter on the western than on the eastern slopes and there are substantial winter snowpacks.

A diverse array of ecosystems and biota are present: savanna-type *Pinus ponderosa* stands at the low elevation steppe-forest ecotone; luxuriant montane forests (including *Tsuga heterophylla* and *Thuja plicata* along with more widespread species such as *Pseudotsuga menziesii* and *Pinus contorta*); subalpine forests and meadows; and

finally alpine landscapes. Notable faunistic elements include the mountain goat (*Oreamnos americanus*), elk, bighorn sheep (*Ovis canadensis*), moose (*Alces alces*) and grizzly bear (*Ursus horribilis*).

Current research includes: ecological studies of the grizzly bear and large ungulates; invertebrate surveys with one ecological study of stoneflies (Plecoptera); visitor impacts in subalpine and alpine areas and their reduction; geology; systematics of some of the floristic components; and impact of aluminum plant emissions on forest insect infestations. A particularly interesting research project involves an inventory of the forest ecosystems using gradient models and a sophisticated information storage and retrieval system; an immediate application of the work is provision for a real-time fire simulation model on which to base fire control decisions.

Great Smoky Mountains National Park

This 207 500-ha Park was established in 1934 and is located in the southern Appalachian Mountains in North Carolina and Tennessee (lat. 35° 43'N, long. 83° 20'W). It is administered by the National Park Service. Topography in this mature mountain region is rugged with elevations ranging from less than 500 m to 1 992 m atop Clingman's Dome. Sedimentary and metamorphic materials predominate--shale, siltstone, slate, limestone, and sandstone. Precipitation and temperatures show marked elevational gradients but average 56.5° F and about 150 cm annually at low elevation stations with much of the rain occurring during the summer growing season.

The outstanding biological feature of the reserve is the dense mantle of vegetation. Richly diverse hardwood forests dominate--*Liriodendron tulipifera*, *Quercus* spp., *Fagus grandifolia*, *Carya* spp., and *Pinus* spp. are characteristic. Subalpine *Picea rubens-Abies fraseri* forests dominate above 1 500 m. Grass and heath balds are conspicuous nonforested areas on some mountain summits and ridges. Biologically the region is the richest in the Eastern Forest Biotic Province.

Much of the current research focuses on systematic, population, and interspecific competition studies of organisms including some groups of vascular plants, fungi, land snails, and especially salamanders. Management-oriented research includes studies of the ecology and impact of the introduced European boar (*Sus scrofa*) and ecology of the black bear (*Ursus americanus*) using radioisotopes to trace movements.

H. J. Andrews Experimental Forest

This 6 100-ha tract was established in 1948 and is located on the western slopes of the Cascade Range in Oregon (lat. 44° 15'N, long. 122° 10'W) and is administered by the U.S. Forest Service. Mature mountainous topography (elevational range 435 to 1 631 m) with moderate to steep slopes is characteristic of this region of Miocene-Pliocene extrusives (andesite, basalt, and other pyroclastics).

The climate is winter-wet, and summer-dry with an annual precipitation of 239 cm and substantial winter snowpack (up to 3 m or more) at higher elevations.

The outstanding ecosystems are dense, virgin forests of *Pseudotsuga menziesii*, *Tsuga heterophylla*, *Thuja plicata*, and *Abies* spp. which are predominantly old growth (>400 years old) and associated streams. Vegetation is zoned with *Pseudotsuga* dominating up to 1 200 m and *Abies* spp. above this elevation. Younger (130-year-old) stands of *Pseudotsuga* and *Abies procera* are also common. Standing crops are often large (1 000 metric tons per ha or more).

Past and current research programs are extensive including long-term Forest Service studies of effects of management practices on water yield and quality and ecosystem analyses (carbon, water, and nutrient cycles) by the Coniferous Forest Biome Project, (U.S.-IBP), which selected the H. J. Andrews as an intensive study site. Current emphases include: structure and function of stream ecosystems along a size gradient (from the allochthonous-dominated first order streams which lack fish to fifth order and larger); energy, nitrogen, and water budgets of old-growth tree canopies; geomorphic processes and erosion (especially mass movements) under natural and managed conditions; ecosystem processes (productivity, decomposition, etc.) along environmental gradients; and nutrient, water, and carbon budgets for natural and treated watersheds.

Hubbard Brook Experimental Forest

The 3 075-ha Hubbard Brook Experimental Forest is located in the White Mountains of New Hampshire (lat. 43° 57'N, long. 71° 42'W) and is administered by the U.S. Forest Service. It was established in 1955 to serve as the intensive site for watershed research in the northern Appalachian Mountains. Terrain is typically steep and rugged with elevations from 230 to 1 010 m. The area was heavily glaciated, and soils are predominantly well-drained podzols on till. Average precipitation in this continental climate is 1 240 cm, well distributed throughout the year; 1/3 to 1/4 of the precipitation occurs as snow which persists from mid-December until mid-April.

The Hubbard Brook drainage was logged over 50 years ago, but the forests today are dominated by representative northern hardwoods. *Fagus grandifolia*, *Betula alleghaniensis*, *Betula papyrifera*, *Acer saccharum*, *Acer rubra*, and *Fraxinus americana* are most important. Ten percent of the trees are conifers--*Picea rubra*, *Abies balsamea*, and *Tsuga canadensis*.

The Experimental Forest is the location for intensive research on water, nutrient, and carbon cycles by scientists from the U.S. Forest Service and several U.S. universities, particularly Cornell and Yale. One major discovery has been that large losses of nutrients can occur when vegetative regrowth is prevented following forest cutting. Losses are less when regrowth is allowed. Effects of acid rain and of forest cutting on water yields and snowmelt floods are also under study along with numerous autecological studies of various plants

and animals and an ecosystem analysis of a small lake. Important forest succession and lake models have been developed using Hubbard Brook data.

Jornada Experimental Range

This 78 297-ha reserve is located in southern New Mexico (lat. 32° 37'N, long. 106° 45'W) and is administered by the Agricultural Research Service (U.S. Department of Agriculture). Annual rainfall in this arid region is about 23 cm of which half falls during July, August, and September. Approximately 79 percent of the reserve is located on the undulating or gentle slopes of the Jornada Plain which consists of unconsolidated pleistocene detritus. The remainder is located on the steep slopes of the St. Andres Mountains which consist of paleozoic marine sediments.

The biota generally segregate according to the major physiographic units. *Bouteloua-Hilaria* shrub steppe occupies 58 500 ha on the playas (800 ha), plains (42 000 ha), and bajadas (15 700 ha) of the Jornada Plain. Dominant grasses on the sandy soils are *Bouteloua eriopoda*, *Sporobolus* spp. and *Aristida longiseta*. Relatively recent brush invasion is common and includes *Prosopis glandulosa*, *Atriplex canescens*, *Gutierrezia sarothrae*, and *Yucca elata*. In lower lying areas with heavier soils, primary grasses are *Hilaria mutica* and *Scleropogon brevifolius* with *Flourensia cernua* as the principal invading shrub. The mountain vegetation types, which cover 16 600 ha, are primarily shrub communities (*Larrea divaricata*, *Prosopis*, *Cerocarpus*, *Acacia*, *Artemisia filifolia*, etc.) and woodlands of *Juniperus osteosperma* and *Pinus cembroides*. Major vertebrates include a large resident mule deer population and a small band of desert bighorn sheep.

Research has been underway at this site since it was established in 1912. In the early years, the focus was almost entirely upon range management problems. Current research efforts, in addition to range and wildlife habitat research, include studies of carbon, water, and nutrient cycles in desert grasslands. The Jornada Experimental Range was used as a major study site by both the Grassland and Desert Biome Projects of the U.S.—IBP.

Luquillo Experimental Forest

This 11 300-ha tract was established in eastern Puerto Rico (lat. 18° 21'N, long. 65° 45'W) in 1903 and is administered by the Institute of Tropical Forestry (U.S. Forest Service). Elevations range from 150 to 1 080 m. Four major ecosystems are recognized: (1) Subtropical Wet Forest on foothills and slopes below 600 m (7 900 ha). Annual precipitation is 175 to 250 cm. In well-developed forests, the average number of tree species is 33 per acre with *Dacryodes excelsa* characteristic; (2) Subtropical Rain Forest or Montane Thicket on valleys and gradual slopes above 600 m (2 000 ha). Annual precipitation is 250 to 450 cm. Two tree strata average 23 tree species per acre with *Cyrilla racemiflora* characteristic;

(3) Palm Brake on steep slopes and arroyos above 450 m (1 200 ha). Soils are usually shallow and unstable and precipitation high (225 cm or more). Sierra palm (*Euterpe globosa*) is characteristic; and (4) Dwarf Forest or Elfin Woodland on the most exposed peaks and ridges above 800 m (240 ha). High winds, precipitation 375 cm or more, and saturated soils are characteristic. The tree canopy is from <1 to >6 m in height with abundant mosses and epiphytes.

The Luquillo is a major site for research on the ecology and management of tropical forests. Management research includes studies of exotic plantations which cover 400 ha. Ecological research inclu[des] studies of the natural communities (e.g., Ewel and Whitmore 1973) an[d] of the very rare Puerto Rican parrot (*Amazona vittata*) which is also the subject of an intensive management program. Ecosystem-level research has been carried out at an intensive site (Odum 1970).

Mount McKinley National Park

This 784 900-ha reserve is located in the Alaskan Range of centra[l] Alaska (lat. 63° 48'N, long. 153° 02'W) and is administered by the National Park Service. Topography is varied including extensive gently undulating or sloping lowlands and rugged, heavily glaciated mountains; the summit of Mount McKinley is, of course, the highest point at 6 194 m, 4 800 m above the surrounding foothills. The climate is severe with long cold snowy winters and short summers.

The major ecosystems within the reserve are tundra communities of various types with *Eriophorum*, *Carex*, *Salix*, and *Betula* species as characteristic components. *Taiga* is relatively limited because the upper timberline occurs at about 825 m. *Taiga* species (*Picea mariana*, *Picea glauca*, *Populus* spp., and *Betula papyrifera*) occur in relatively narrow strips along river valleys. The ungulates and large predators are a notable feature of the reserve and include caribou, Dall sheep (*Ovis dalli*), moose, wolves, and grizzly bear. Current research is focused most heavily on the faunistic components- their ecology and food habits and carrying capacity of the ecosystem for ungulates such as moose.

Noatack National Arctic Range

This 3 000 000-ha tract is representative of the Alaskan Tundra Biotic Province. It has been proposed for addition to the National Wildlife Refuge system and is currently administered jointly by the Bureau of Land Management and Fish and Wildlife Service with the advice of the National Park Service (all agencies in the U.S. Department of the Interior). It is located in northwestern Alaska just no[rth] of the Arctic Circle and consists of two major arctic river valleys- those of Noatack and Squirrel Rivers (lat. 67° 58'N, long. 162° 15'W) Elevations range from sea level to over 2 400 m. Topography is generally rolling except near the headwaters. Paleozoic sedimentary and metamorphic rocks dominate, and permafrost and periglacial phenomena occur throughout. Noatack has been described as similar to the Anadyr region of eastern Siberia.

Tundra dominates with tussock and shrub tussock communities the most common form. *Eriophorum vaginatum* is the major vascular plant. Fell fields and barrens with open discontinuous vegetation are second in importance to tussock communities. Tundra brush communities are also common and consist of *Betula nana*, *Salix pulshra*, or riparian willow (*Salix* spp. and *Alnus crispa*) types. *Taiga*, consisting of *Picea glauca* stands, occur as far north as the Noatack River. *Populus* groves occur in protected locations.

Wildlife is abundant including 200,000 migrants from the Arctic caribou herd, grizzly bear, Dall sheep, moose, wolverine, and wolf. The most northerly chum salmon run occurs in this Biosphere Reserve.

Scientific expenditions have been conducted to the area, but no permanent research programs or facilities are presently located there. In addition to unpublished reports of expeditions or survey teams, much relevant information has been published in connection with the Cape Thompson investigations (Wilimovsky and Wolfe 1966) and in individual scientific reports.

Olympic National Park

This 362 850-ha reserve is located on the Olympic Peninsula of northwestern Washington State (lat. 47° 54'N, long. 123° 00'W) and is administered by the National Park Service. The majority of the area is a rugged mountainous region of varied bedrock geology, steep slopes, and extensive evidences of glaciation. A part of the reserve is a narrow strip on the coastal plain along the Pacific Ocean; topography is moderate in this section. Elevations range from sea level to 2 428 m atop Mount Olympus. Despite the relatively low elevation of the mountains several peaks currently have significant alpine glaciers. This is a consequence of the very wet, cool climate of this coastal region. Precipitation reaches 500 cm on Mount Olympus and is nearly as heavy in the western valleys; it declines rapidly on the eastern (lee) slopes of the mountains.

The outstanding biological features of the reserve are the dense coniferous forests, which occupy all but the highest peaks and ridges, and the herds of Roosevelt elk (*Cervus canadensis roosevelti*). The forests of the western valleys are most distinctive--the so-called "Olympic Rain Forests" of *Picea sitchensis*, *Tsuga heterophylla*, and *Acer macrophyllum* (Franklin and Dyrness 1973). *Pseudotsuga menziesii* is a common associate on the western slopes as is *Thuja plicata* on the coastal plain. *Abies amabilis-Tsuga heterophylla* forests dominate the interior of the Olympic Mountains and *Pseudotsuga* and *Tsuga* the drier montane forests of the eastern slopes (Fonda and Bliss 1969). Subalpine forests and meadows are common above about 1 500 m.

Current research includes studies of: ecology of non-native mountain goat populations, human impact, particularly in subalpine and alpine regions, mass balance of Blue Glacier, ecology of several small mammals, and succession and environmental relations in forests and subalpine meadows and at timberline.

Organ Pipe Cactus National Monument

This 134 000-ha reserve is located in southern Arizona along the Mexican border (lat. 32° 14'N, long. 113° 05'W) and is administered by the National Park Service. Varied topographic conditions exist from gentle valleys and plains to jagged ridges and peaks with deep canyons. About half of the 24 cm of annual precipitation occurs from July through September. Temperatures of 35 to 40°C are common in the summer; subfreezing nighttime temperatures occur occasionally during the winter.

Several types of desert ecosystems are generally recognized. Upland Arizona succulent deserts in the eastern half of the monument are characterized by cacti including *Carnegiea gigantea* (saguaro), *Lemaireocereus thurberi* (organ pipe), *Opuntia* spp. (prickly pears and chollas), *Ferocactus* spp. (barrel), *Echinocereus* spp. (hedgehog), and *Mammillaria* (pincushion). *Agave* spp. are common along with several desert "trees" such as *Olneya tesota* (ironwood), *Cercidium* spp. (paloverde), and *Acacia* spp. The central Gulf Coast phase of the Sonoran Desert, which is also present, contains additional unusual plants such as *Bursera microphylla* (elephant tree) and *Lophocereus schottii* (senita cactus). California microphyll desert is characterized by *Larrea tridentata* and *Franseria* spp.; it is found on the western edge of the monument. A distinctive desert fauna is present including many reptiles (e.g., 27 snake taxa and the desert tortoise, (*Gopherus agassizi*).

Rocky Mountain National Park

This 106 160-ha reserve is located astride the crest of the Rocky Mountains in north central Colorado (lat. 40° 29'N, long. 106° 06'W). It is administered by the National Park Service. Steep mountain slopes with extensive evidence of glaciation are the most prominent biological features; elevation ranges from about 2 400 to over 4 000 m on some peaks along the crest of the Rocky Mountains.

The major ecosystems present are the montane and subalpine forests and extensive tracts of alpine tundra. Montane forests are typified by *Pinus ponderosa* and *Juniperus* at lowest elevations and by *Pseudotsuga menziesii* and *Pinus contorta* at middle elevations. Above 2 700 m, subalpine forests of *Picea engelmannii*, *Abies lasiocarpa*, and *Pinus flexilis* dominate. Alpine ecosystems are varied, but a tundra of *Koeleria cristata*, *Carex* spp. and other herbs is most characteristic. Among the distinctive ungulates are elk, mule deer, and bighorn sheep. Current research includes: a 15-year study of alpine tundra recovery following human trampling, several geologic studies, ecological studies of ungulates and several bird species, ungulate habitat condition and trends, ecology and epidemiology of vector-borne diseases, and an inventory of aquatic resources.

San Dimas Experimental Forest

San Dimas is a 6 947-ha tract located in the San Gabriel Mountains of southern California (lat. 34° 12'N, long. 117° 46'W) and administ

by the U.S. Forest Service. This area has a typical Mediterranean climate with mild, wet winters and hot, dry summers (mean annual precipitation 67 cm). Topography (elevational range 381 m to 1 615 m) is generally steep (average slope 68 percent) and extensively dissected by steep-walled canyons; metamorphic and granitic formations dominate.

Vegetation types are: 47-percent chamise chaparral (*Adenostoma fasciculatum*, *Ceanothus crassifolius*, and *Arctostaphylos glauca*); 24-percent scrub oak (*Quercus dumosa*, *Q. wislizenii*, *Ceanothus oligathus*, and *Cercocarpus betuloides*); 12-percent sage and barren areas (*Salvia apiana* and *Eriogonum fasciculatum*); 7-percent riparian woodland (*Alnus rhombifolia*, *Acer macrophyllum* and *Umbellularia californica*); and the remainder in woodland sage (*Quercus/Salvia*), mixed chaparral, and *Pseudotsuga macrocarpa*. A 554-ha control area (Fern Canyon Research Natural Area) incorporates examples of all of these types. Most of the Experimental Forest was burned by wildfire in 1960 (a natural phenomenon for the type) and successional development is well understood. Characteristic vertebrates are mule deer and dusky-footed woodrat (*Neotoma fuscipes*).

Mooney and Parsons (1973) in their overview of research programs at the site describe San Dimas as probably the best known Californian Mediterranean ecosystem; intensive research has been underway since 1934. The hydrologic cycle was and continues to be a major focus including rainfall patterns in mountainous terrain, water use by vegetation, recovery following wildfire, and erosional processes (rates under natural conditions can average as high as 8 500 kg/ha). In recent years, overall carbon and nutrient budgets and ecology of individual species have received increased attention.

San Joaquin Experimental Range

This 1 861-ha area is located in the Central Valley region of California (lat. 37° 05'N, long. 129° 43'W) and is administered by the U.S. Forest Service. It has a Mediterranean climate with an average annual precipitation of 45 cm (range 22 to 90 cm). The site occupies rough granitic foothills ranging from 213- to 518-m elevation along the western slopes of the Sierra Nevada Mountains. Primary vegetation types are annual grasslands (*Bromus* spp., *Festuca* spp., *Erodium* spp., and *Trifolium* spp.) at lower elevations and oak woodlands (*Quercus* spp. and *Pinus sabiniana*) at higher elevations.

This area was established in 1934 and has been extensively used for range management research. Current programs include: wildlife ecology in annual grasslands, above- and below-ground biomass production, invertebrate populations and consumption, decomposition; relationship between abiotic factors and ecosystem processes, vegetation and cattle responses to various management strategies, and development of improved plant varieties for rangeland seeding. Much of the current ecosystem work was developed and is being carried on as one of the coordinating sites in the Grassland Biome Project (U.S.—IBP).

Sequoia-Kings Canyon National Parks

This 342 754-ha reserve consists of two adjoining Parks which are administered by the National Park Service. They are located in the central Sierra Nevada mountains of California (lat. 36° 52'N, long. 118° 93'W), a rugged topographic region composed mainly of granitic rock. The general elevation is 1 300 to 4 000 m in Kings Canyon National Park and 500 to 4 200 m in Sequoia National Park. The climate is summer-dry and winter-wet with strong elevational effects on precipitation and temperature. Heavy winter snowpacks develop at higher elevations.

The dominant biological features of both Parks are the montane and subalpine forest ecosystems. The montane forests are mixtures of *Pinus lambertiana*, *P. ponderosa*, *Libocedrus decurrens*, and *Abies concolor*. In subalpine regions, forests of *Abies magnifica*, *A. concolor*, *P. contorta*, and *P. jeffreyi* are characteristic with *Tsuga mertensiana* and *P. albicaulis* near timberline. *Sequoiadendron giganteum* is a distinctive but scattered element of the montane mixed coniferous forests. Meadows and lakes are abundant at higher elevations. Research includes ecological studies of: *Sequoiadendron* (Hartesveldt et al. 1975), including some unusual studies of associated insects; *Quercus kelloggii*; mountain meadow origin and development; and several vertebrates such as black bear, bighorn sheep, and cougar (*Felis concolor*); and limnology of high lakes (including human impact). The role of wildfire in forest and chaparral ecosystems has received special emphasis, and there are pilot projects on use of controlled burns to restore natural conditions and to encourage *Sequoia* regeneration and on development of "let-burn" programs to limit wildfire control activities.

Stanislaus Experimental Forest

This is a relatively small (683-ha) reserve located on the western slopes of the Sierra Nevada mountains in California (lat. 3[illegible] 03'N, long. 19° 57'W). It is administered by the U.S. Forest Servi[illegible] The site experiences cool, wet winters and dry, hot summers. Topography is rough with moderate to steep slopes, rounded ridges, saddl[illegible] and moderately deep canyons. The soils are derived from granite, a[illegible] much of the area has been glaciated. Elevations range from 1 585 t[illegible] 1 951 m.

Biologically, this area is considered to be representative of th[illegible] Sierran mixed-conifer type which is dominated by *P. lambertiana*, *Abies concolor*, *P. ponderosa*, *P. jeffreyi*, and *Libocedrus decurrens*. At higher elevations, subalpine *A. magnifica* forests are encountere[illegible] Forest structures are quite complex. Associated species include *Alnus rhombifolia* along streams, *Cornus nuttallii* in the understory, and numerous brushy *Arctostaphylos* and *Ceanothus* species. Research was begun in this area in 1909, and this is probably the most intensively studied example of Sierran mixed-conifer forests. Most of the research was centered upon silvicultural problems such as regeneration of the important tree species and forest insect and diseases.

Three Sisters Wilderness

This 80 900-ha reserve was established as a Wilderness by Congress in 1964. It is located astride the crest of the Cascade Range in central Oregon (lat. 44°N, long. 121°W) and administered by the U.S. Forest Service. Topography in this region of Pliocene-Pleistocene volcanic rocks consists largely of a gently sloping plateau although steep, rugged slopes are encountered along major stream courses and on the slopes of glaciated valleys and individual volcanic cones and buttes. Elevations range from about 600 m on the west boundary to 3 000 m atop the Three Sisters (three large composite volcanoes) and around 1 600 m on the east boundary. Mild, wet winters and dry, cool summers are characteristic with snowpacks of 3 to 5 m or more developing in the subalpine and alpine regions (locations over 1 500 m in elevation); snowpacks may persist into August in these areas.

Several contrasting ecosystems are present. In the western third of the reserve, dense forests of *Pseudotsuga menziesii* and *Tsuga heterophylla* are characteristic and are broadly similar to stands found on the nearby H. J. Andrews Experimental Forest. At higher elevations are subalpine forests of *Tsuga mertensiana* and *Abies* spp., subalpine meadows, alpine rockfields, permanent snowfields, and glaciers. Subalpine lakes are abundant. East of the summit, in the rain shadow of the Cascade Range, mixed conifer forests of *Pinus contorta*, *Pseudotsuga menziesii*, *Abies grandis*, and *Pinus ponderosa* are encountered. *Pinus albicaulis* is a major timberline associate of *Tsuga mertensiana* in this area.

Virgin Islands National Park

This 6 130-ha reserve provides for representation of the Lesser Antillean Biotic Province and has been administered by the National Park Service since designation as a National Park in 1956. It is located on St. John Island (lat. 18° 15'N, long. 64° 00'W) most of which has, unfortunately, been disturbed since first settlement in 1718. The Park includes a large area of lush, second-growth tropical forest (a mixture of native and introduced plants), coral reef gardens, and offshore rocks and caps. St. John is of sedimentary and volcanic origin with a maximum elevation of almost 400 m. Average rainfall is about 100 cm. The reserve has an extremely rich biota including a broad array of tropical trees and other plant life forms, over 100 bird species, and coral-dwelling marine organisms.

Yellowstone National Park

This 900 000-ha reserve needs little introduction. Established as the first National Park in 1872 it is administered by the National Park Service. Yellowstone is located at high elevations (1 620 to 3 408 m) along the crest of the Rocky Mountains (lat. 44° 45'N, long. 110° 35'W) primarily within northeastern Wyoming. Much of the Park is a series of high rolling plateaus with volcanic activity as the primary agent of landscape creation and erosional processes (including glaciation) as a secondary agent.

Geyser basins, hot springs, and other geothermal features are prominent; this is the only existing U.S. Biosphere Reserve which was selected for its unique (geothermal) features and not as a representative of a biogeographic province. There are, however, significant biological features within the reserve including extensive montane forests (especially of *Pinus contorta*), many birds, and populations of well-known ungulates and large predators such as bison (*Bison bison*), elk, moose, pronghorn antelope, bighorn sheep, mule deer, and black and grizzly bear.

Despite the large numbers of visitors, large segments of the Park remain in a virgin state and are rarely visited. Current research includes an array of geological studies (including thermal, volcanic and seismic aspects), ecological studies of fauna (including trout, raptors, grizzly bear, and aquatic birds), climatology, several studies on the ecology of thermal environments such as hot springs, forest classification and succession, and heavy metal pollution.

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Biosphere Reserves in the United States and Their Relationship to the International Program, Man and the Biosphere

by

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INTRODUCTION

The focus of the Man and the Biosphere (MAB) Project No. 8--Conservation of Natural Areas and of the Genetic Material They Contain--is on the development of an international network of biosphere reserves representative of the biogeographic provinces of the world (UNESCO 1974). This project is based on the recognition that conservation of natural areas is of vital importance to the world for the role that these areas can play in scientific research, monitoring, education, and training, and in conservation of gene pools of plants and animals. It is also based on the view that, in the long term, ecosystem conservation can only succeed if we understand how these systems function with and without the presence of various human activities. Only long-term research and monitoring of man's actions can determine which of these actions are compatible with maintaining viable ecosystems and genetic diversity. The MAB Program is concerned with the impacts and ecological effects of human activities on different types of ecosystems or physiographic units, and countries are now developing cooperative interdisciplinar research programs (UNESCO 1975). Experts involved in the preparatio of the MAB projects have emphasized the need for further studies of natural ecosystems and for comparison studies and experimental research on variously modified ecosystems. Biosphere Reserves, which can include both natural and modified ecosystems are basic logistic resources for much of the research to be undertaken in MAB.

PROGRESS IN THE INTERNATIONAL MAB PROJECT NO. 8

A great deal of progress has already been made toward developing this international network of biosphere reserves. As of December 1975, 38 countries have proposed to United Nations Educational, Scientific, and Cultural Organization (UNESCO) a total of approximately 155 areas to be designated as biosphere reserves. Also, work sponsored by UNESCO, the International Union for the Conservation of Nature and Natural Resources (IUCN) and the United Nations Environmental Program (UNEP) has progressed on the classification of natural regions, regional and country surveys, and identification of areas appropriate for establishment as biosphere reserves.

Surveys are underway, or have recently been completed in Southeast Asia, eastern Africa, western Africa, Central America, north and west Europe, and in coastal ecosystems of the Mediterranean and northern Indian Ocean.

Another noteworthy development is that during 1975 an "Ecosystem Conservation Group" was established with representation from UNEP, UNESCO, IUCN, and the Food and Agricultural Organization. This group will have regular meetings to facilitate closer cooperation between these organizations in their programs relating to ecosystem conservation. The Biosphere Reserve Project is considered to be a joint effort of these organizations.

The considerable progress in the international development of MAB Project 8 has been due, in part, to the stimulus of the July 1974 U.S.-U.S.S.R. agreement to contribute to the implementation of the MAB Program. This agreement implemented designation of certain natural areas as biosphere reserves in which research will be conducted in conformity with the goals of the UNESCO program.

BIOSPHERE RESERVES IN THE UNITED STATES

The approach to developing a network of biosphere reserves in the United States is outlined under the basic purposes of these reserves which are identified as follows (UNESCO 1974):

A. Conservation or preservation:

> "To conserve for present and future use the diversity and integrity of biotic communities of plants and animals within natural ecosystems, and to safeguard the genetic diversity of species on which their continuing evolution depends."

Plans for developing a realistic network of reserves representative of the many biotic regions found in the United States will be carried out by Federal, State, local and private authorities. The U.S. MAB Directorate will work closely with such groups as the Federal Committee on Ecological Reserves and The Nature Conservancy in determining the range of existing public and private efforts to protect our natural areas and will recommend actions for a coordinated national program. The U.S. Directorate has begun by designating some of the best and most representative areas in the U.S. as biosphere reserves. These areas either have, or can develop with a few years, the capability to participate effectively in cooperative national and international MAB activities. On this same basis, a few additional areas will be selected as biosphere reserves.

In September 1976, the U.S. MAB Project No. 8 will begin a series of regional meetings in which each biosphere reserve unit (experimental and baseline areas) will develop management and research plans as part of a national system. Plan development for units of the network must include recognition of the legislative

mandates and administrative policies characteristic of each managing agency or organization participating in the system. Plans will include special provisions to relate activities of the United States program to activities of other countries that are participating in MAB 8. Several fundamental provisions are essential for each unit, such as: (1) a biosphere reserve plan that identifies and defines appropriate land use conditions and that is based on professionally conducted programs of research, (2) the creation of public awareness of the nature, purposes, and management objectives of the unit and (3) the establishment of appropriate types of uses of the unit for environmental education and cooperative research programs.

An example of one type of activity which U.S. MAB has already undertaken is in the development of guidelines for management and conservation of coastal ecosystems. The work is based on extensive research and management experience in the protection of coastal areas. U.S. MAB proposes to assist in a UNESCO/UNEP MAB project to develop guidelines for the management of coastal zones, within biosphere reserves of other types of protected sites, which will be based on case examples of research and experience in a variety of coastal ecosystem types (Dolan, et al., 1975).

B. Research and monitoring:

> "To provide areas for ecological and environmental research including, particularly, baseline studies, both within and adjacent to such reserves, such research to be consistent with the conservation objective."

In addition to activities discussed in other papers presented at this Symposium, the U.S. MAB Project 8 activities this year will include an inventory of research and monitoring activities currently being conducted and the development of plans for addition studies. An important element of these activities will be cooperative work under Project V-4.1, Biosphere Reserves, of the U.S.-U.S.S.R. Bilateral Agreement on Environmental Protection.

Research projects that are suggested for MAB Project 8 include:

(1) Ecosystem inventory and analysis (structure, function, stability, diversity, mineral and energy flows, modeling, etc.);
(2) Development of a means to test the representativeness of proposed biosphere reserve units;
(3) Examination of factors that influence the probability that a given unit will succeed in preserving the genetic material it contains. One activity that is being considered has to do with applications of biogeographical theory to reserve design and management. Its objectives would be to:

a. Apply current predictive theory to park and preserve situations to test theory validity;
b. Predict community structural changes likely to occur in preserves; and
c. Formulate design guidelines and management schemes which will maintain a steady state and minimize extinctions within animal preserves.

(4) Refinement and application of modeling techniques to permit prediction of future needs for data that will be derived from monitoring activities to be initiated.

Research and monitoring plans for biosphere reserves will be developed to consider the reserve's potential role in long term synoptic monitoring of the international network of reserves. Recommendations will also be developed for use of biosphere reserves as baseline areas for monitoring of terrestrial ecosystems in the Global Environmental Monitoring System of UNEP.

The multi-agency, multi-year, multi-project nature of the biosphere reserve program requires use of modern, easily updated, comprehensible, and flexible data handling systems. A major task for the U.S. MAB Committee during the coming year will be to consider the feasibility of developing an information management system suitable for ensuring both short and long term storage, retrieval, and manipulation of information

C. Education and Training:

"To provide facilities for education and training."

OBJECTIVES

The International Coordinating Council of MAB has emphasized that all MAB research projects should include students and have a strong training component and that education and training courses should be organized to permit student exchange between countries. The Council also suggested that exchange of students, teachers, training specialists, and scientists between MAB projects should be encouraged. In support of these recommendations, the U.S. Directorate for MAB Project 8 will emphasize the following:

(1) On-site training and environmental education in Biosphere Reserves. Model programs have been developed in National Environmental Study Areas in some of the biosphere reserves, and student and teacher training materials are available for field projects (U.S. Department of the Interior, National Park Service, 1972);
(2) Further incorporation of MAB information and concepts into appropriate existing programs of government agencies and private institutions and strengthening of these programs to convey information about MAB nationally and internationally.

An example is the International Seminar on Administration of National Parks and Equivalent Reserves sponsored by the School of Natural Resources, University of Michigan with cooperation of National Park Service, United States Department of the Interior; Parks Canada, Department of Indian and Northern Affairs, Canada; and the National Commission of Public Works in Natural Parks, Secretary of Public Works, Republic of Mexico. The seminar, which is held each year in August, includes visits to parks and reserves in the United States, Canada, and Mexico.

The Seminar is designed for administrators, professional personnel and conservation leaders responsible for the establishment and development of park and reserve systems and associated programs throughout the world. This program now includes MAB seminars and visits to biosphere reserves.

(3) Preparation of audiovisual and informational materials on MAB especially on the national and international network of biosphere reserves.

It is suggested that the U.S. and the U.S.S.R. exchange such materials for purposes of developing information programs on Project V-1.1.

CONCLUSION

Biosphere reserves are a means to strengthen existing national and international research and conservation programs. The strength of the concept, unlike that of most nature conservation programs, lies in the integration and use of biosphere reserves as part of the national and international MAB program.

The United States will develop a number of areas to serve as bases for participation in a national and international program oriented to research, conservation, education, and training.

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APPENDIX

United States Man and Biosphere (MAB) Project Areas (Nov. 1977)

Following is a list of the 14 MAB project areas (Directorates) and a brief explanation of their emphasis in the United States. Also included with each project is the name of the U.S. Directorate Chairman.

1. *Tropical Forests:* Ecological effects of increasing human activities on tropical and subtropical forest ecosystems. A conceptual model for tropical forest management will be developed, using available information and defining specific inputs and outputs in ecological and economic terms.

Chairman: Frank B. Golley, Executive Director, Institute of Ecology, University of Georgia, Athens, Georgia 30601.

2. *Temperate Forests:* Ecological effects of different land uses and management practices on temperature and mediterranean forest landscapes. Baseline environmental monitoring programs and analyses of the effects of changing environmental conditions will be used to develop alternative management strategies for multiple use of temperate and mediterranean forest ecosystems.

Chairman: David Reichle, Associate Division Director, Environmental Sciences Division, Oak Ridge National Lab., P.O. Box X, Bldg. 2001, Oak Ridge, Tennessee 37830.

3. *Grazing Lands:* Impact of human activities and land use practices on grazing lands--savanna and grassland (from temperate to arid areas). The existing condition and potential of grazing lands will be determined, and physical, biological, environmental, and socio-economic effects of conflicting uses will be determined.

Chairman: David B. Thorud, Assistant Director, Southeastern Forest Experimental Station, P.O. Box 2570, Asheville, North Carolina 28802.

4. *Arid Zones:* Impact of human activities on the dynamics of arid and semi-arid ecosystems. Causal relationships in arid land degradation will be analyzed with the view toward development of long range strategies for arid land development consistent with carrying capacities, weather conditions, and research utilization.

Chairman: Jack Johnson, Director, Office of Arid Lands Studies, University of Arizona, 845 N. Park Avenue, Tucson, Arizona 85710.

5. *Fresh water:* Ecological effects of human activities on the value and resources of lakes, marshes, rivers, deltas, estuaries, and coastal zones. Research, education, and training activities will be used to develop management strategies that will provide a predictive capability for establishing the quality and quantity of water available, and identify conflicts that will arise because of limited local or regional supplies.

Chairman: (5A--Inland Resources) Edward Fernald, Florida Resources & Environmental Analysis Center, Florida State University, Tallahassee, Florida 32306.

Chairman: (5B--Coastal Resources) Jack R. Van Lopik, Dean, Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana 70803.

6. *Mountains:* Impact of human activities on mountain and tundra ecosystems. Emphasis will be given to development of techniques for prediction of carrying capacity of mountain ecosystems for multiple use, including tourism. Analysis of the ecological and socio-economic impacts of tourism, industrial development, and resource exploitation will be examined in high latitude areas.

Chairman: (6A--Mountains and Tundra--Low Latitudes) Jack Ives, Director, Institute of Arctic & Alpine Research, University of Colorado, Boulder, Colorado 80309.

Chairman: (6B--Arctic) Robert B. Weeden, University of Alaska, Fairbanks, Alaska 99701.

7. *Islands:* Ecology and rational use of island ecosystems. Environmental and socio-economic changes associated with tourism and industrial development will be examined in order to develop improved strategies to preserve some of the features of these fragile ecosystems consistent with human needs.

Chairman: (7A--Pacific) Roland W. Force, 320 E. 65th Street, New York, New York 10021.

Chairman: (7B--Caribbean) William S. Beller (EPA), 2701 Largo Place, Bowie, Maryland 20715.

8. *Biosphere Reserves:* Conservation of natural areas and of the genetic material they contain. The 28 Biosphere Reserves established thus far in the United States are part of an international system of reserves with the primary objectives of conservation of genetic diversity, baseline environmental research and monitoring.

Cochairmen: (Conservation) Carl M. Berntsen, Director, Timber Management Research, U.S. Forest Service, Department of Agriculture, Washington, D.C. 20520; Vernon C. Gilbert, Associate Chief Scientist, National Park Service, Department of the Interior, Washington, D.C. 20240.

9. *Pesticides/Fertilizer:* Ecological assessment of pest management and fertilizer use on terrestrial and aquatic ecosystems. Included here are studies of methods of transport; behavior and reactions of specific compounds in water and terrestrial environments are related to their physical properties; protective clothing; specific formulation of pesticides to reduce environmental contamination; and disposal of contaminants.

Chairman: Virgil H. Freed, Director, Environmental Health Science Center, Oregon State University, Corvallis, Oregon 97331.

10. *Engineering Works:* Effects on Man and his environment of major engineering works. Attention will be given to concerns which arise in a wide variety of engineering applications including: siting for environmental protection; displacement and relocation of populations including the questions of equity; evaluation of effects; and improved predictive techniques to assist in decision strategies.

Chairman: C. P. Wolf, Environmental Psycology Program, CUNY Graduate Center, 33 W. 42nd Street, New York, New York 10036.

11. *Urban Ecosystems:* Ecological aspects of urban system with particular emphasis on energy utilization. The initial thrust will be concerned with water management in urban systems, emphasizing human well-being, land use, and energy considerations.

Chairman: Brian Mar, Associate Dean, College of Engineering, FX-10, University of Washington, Seattle, Washington 98105.

12. *Demographic Change:* Interactions between environmental transformations and the adaptive, demographic, and genetic structure of human populations. Two dimensions of human population change will be examined including: rural urban migration and changes in human populations in the new and old environments; changes in health and welfare of human population in existing communities impacted by environmental change (e.g., tourism and industrial development in Samoa).

Chairman: Peter Kunstadter, East-West Center, 1777 East-West Road, Honolulu, Hawaii 96822.

13. *Perception of Environmental Quality:* Analysis of subjectively perceived environments is necessary to understand human well-being within any given environment. This project will be concerned with human perception of environmental hazards, environmental change, and environmental quality.

Chairman: Joachim F. Wohlwill, Division of Man-Environment Relations, S-126 Human Development Building, The Pennsylvannia State University, University Park, Pennsylvania 16802.

14. *Pollution:* Develop a clearer understanding of the relation of pollution to the structure and functioning of terrestrial and associated aquatic ecosystems. Baseline information will be gathered through state-of-the-art measurements and observations and used to assess current environmental problems and predict future trends.

Chairman: Kenneth Hood, Office of Research and Development, EPA, 401 M Street, SW., Room 621, RD 683, Washington, D.C. 20460

Characteristics of Research Programs at Established U.S. Biosphere Reserves

by

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INTRODUCTION

The ultimate objective of the Biosphere Reserve Project is to attain a coordinated network of Biosphere Reserves representative of the major ecosystem types, linked by exchange of information and scientists. The specific objectives defined by the Man and the Biosphere (MAB) Task Force on Biosphere Reserves (UNESCO 1974) are:

1. "To conserve for present and future human use, the diversity and integrity of biotic communities of plants and animals within natural ecosystems, and to safeguard the genetic diversity of species on which their continuing evolution depends."

2. "To provide areas for ecological and environmental research including baseline studies, both within and adjacent to these reserves, such research to be consistent with the first objective."

3. "To provide facilities for education and training."

The component sites within the Biosphere Reserves should include representative and unique natural and man-modified areas of significant biomes.

The preservation of biotic diversity (Nature Conservancy 1975), provision for monitoring networks, and the maintenance of genetic diversity (Thompson 1975) are all important attributes of the Biosphere Reserves. This paper, however, will deal specifically with existing and potential ecological research programs at existing U.S. Biosphere Reserves. Before presenting a description of these studies, it is appropriate to characterize the unique potential contributions of a research site network.

Some research endeavors are most appropriately conducted under laboratory conditions, but most ecological theory arises from and is ultimately tested with studies from natural or modified ecosystems. The mandate for adequate field research opportunities

[1] At the time this work was accomplished the author was Program Director, Ecosystems Studies Program, National Science Foundation, Washington, D.C.

ises from the realization that man's long-term existence is edicated upon a comprehension of this ecological theory.

The establishment and maintenance of relatively large, diverse tes representative of each major biotic province confers a number characteristics essential for future comprehensive ecological search endeavors:

1. At this point in time, it is impossible to anticipate and fine the field situations and basic data necessary to answer ture questions about the structure and function of ecosystems. , carefully chosen sites, with accompanying information selected om past experience, will preserve our research options and provide opportunity to test new hypotheses and management options.

2. Comparable information generated from a number of research eas will provide a data base from which to make ecological neralizations and propose rational research management strategies.

3. Continuous information from both biotic and abiotic parameters ll permit the potential for detecting subtle degenerating environ-ntal conditions before more overt and non-recoverable diminished vironmental quality becomes evident.

4. Consistent long-term data on biotic and abiotic parameters ll not only allow the separation of short-term fluctuations from ng-term trends but will eventually show correlative relationships tween and among chemical, physical, and biological factors.

5. As we now understand the behavior of ecological systems, there e certain basic driving variables which must be measured to permit e subsequent interpretation of research results. Biosphere Reserve tes, where these basic variables are routinely measured, will present an economy in equipment and the opportunity to produce a iform data base.

6. Restudy of a situation after a period of time may be extremely nformative. This is especially true when the insults imposed on he system have changed or when the ecosystem itself is undergoing emporal or spatial changes. Established sites with driving variable ata over the intervening years are essential for these studies.

7. Ecological research has now progressed in complexity so that any studies require expertise in a number of scientific disciplines, .g. mathematical modeling, statistical methods, and analytical hemistry techniques. Established research sites function as esearch centers where expertise is shared with the greatest fficacy.

8. The convergence of scientists at one site enhances the esulting investigations in a number of ways. Since the site acts s a focal point, there is common ground for initial discussion and ontemplation by scientists from different backgrounds. Many of ur most fruitful research efforts are in the realms of inter-isciplinary projects. At a site where all investigators are closely

associated, the communication channels are short-circuited so the ponderous procedures of scientific publications are obviated. All experiments utilizing a variety of interests and areas of expertise are conveniently organized and conducted. Finally, the probability for serendipitous discoveries from concurrent or spatially related studies are greatly enhanced.

The purpose of listing these eight points is to demonstrate that the Biosphere Reserve concept can augment international research potential from the standpoint of both the individual sites and from the collective array. The remainder of the paper will utilize some example studies to substantiate this contention. The chosen studies are primarily at the ecosystem level, since they most effectively depict the integrative possibilities at and between Biosphere Reserves.

EXAMPLES OF RESEARCH PROJECTS AT U.S. BIOSPHERE RESERVES

The following paragraphs will portray parts of the research programs from five U.S. Biosphere Reserves. The specific sites were selected as examples from different biotic provinces to demonstrate research at some of the more active sites.

Name	State	Location
Hubbard Brook Experimental Forest	New Hampshire	Northeast
H. J. Andrews Experimental Forest Willamette National Forest	Oregon	Northwest
Coweeta Hydrological Laboratory and Experimental Forest, Mantahala National Forest	North Carolina	Southeast
Central Plains Experimental Range	Colorado	Central Pla
Big Bend National Park	Texas	Southwest

Hubbard Brook Experimental Forest

One of the earliest site-oriented ecosystem studies is the Hubb Brook Ecosystem Study which began about 1963 and has continued to the present. The Experimental Forest is in the White Mountains of north-central New Hampshire, ranging in altitude from 229 to 1 015 and covering 3 076 ha of rugged terrain. The nearly mature forest is characterized by uneven-aged, well stocked, second-growth northern hardwoods maple (*Acer*) and beech (*Fagus*) with most coniferous spe (*Tsuga*, *Picea*, *Abies*) at higher elevations and on north-facing slopes. The climate has short, cool summers and long, cold winte Annual precipitation averaged about 123 cm, of which one-third to one-fourth is snow (Likens and Bormann 1975).

This site was ideally suited for the development of watershed input-output nutrient budgets because the watershed substrate is relatively impervious, the climate is moist, and biological communities are embedded in a much larger area of the same type of native vegetation. As a result, by keeping records of meteorological inputs, geological outputs, and transfers within the system, it was possible to build nutrient budgets and calculate the geological losses.

The biota and soils of the ecosystem were found to have developed a major, stabilizing influence on the output of nutrients measured as loss in the drainage waters. Even though the stream discharge ranged over four orders of magnitude during an annual cycle, the weekly chemical concentrations remained relatively constant for magnesium, sulfate, chloride, and calcium (Likens et al. 1967). Aluminum, nitrate, hydrogen ion, and potassium concentrations were slightly increased with increased discharge (Johnson et al. 1969). In the summer, biological activity appreciably reduced the concentration of nitrate and potassium in the stream water. Potassium was found to be the most sensitive index of annual biologic activity of the major alkalies and alkaline earths. Its concentration in stream water sharply decreased during periods of plant growth and increased with plant dormancy (Likens and Bormann 1975).

The deforestation study at Hubbard Brook is one of the best known ecosystem studies in the U.S. In 1965, all the vegetation on one of the experimental watersheds was cut, and the vegetation regrowth was inhibited for three summers by the periodic application of herbicides. This experimental manipulation was designed to determine the effects of (a) quantity and quality of stream water output from the watershed, and (b) fundamental biological and chemical relationships within the intrasystem cycle of the forest ecosystem. A number of modifications were studied, but in summary, the flow of the discharge stream was increased 1.4 times, mostly in the summer, the output of particulate matter was up about 4 times, the net output of dissolved inorganic substances was up 14.8 times and the pH of the stream water was down from 5.1 to 4.3 (Likens et al. 1970). In addition to characterizing the basic responses to ecosystem manipulation, a whole host of interesting mechanistic questions have arisen from this study and a number of subsequent experiments are being conducted. These studies represent the type of ecological research which can and is being conducted on Biosphere Reserves. Not only is the resulting information of intrinsic ecological interest, but it is essential for rational planning of resource management.

H. J. Andrews Experimental Forest

The H. J. Experimental Forest occupies 6 [illegible] ha and is broadly representative of the habitats along the northwestern coast of North America, the region known for its dense coniferous forests and rugged mountainous topography. The climate is maritime, wet with relatively mild winters and dry, cool summers. The vegetation is in two general zones with the lower one dominated by Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and

and western redcedar (*Thuja plicata*), and the upper one dominated by silver fir (*Abies amabilis*), noble fir (*Abies procera*), mountain hemlock (*Tsuga mertensiana*), and Douglas-fir.

The nitrogen budget of a small watershed dominated by old-growth Douglas-fir on the H. J. Andrews Experimental Forest was studied by a team of five investigators. The first step was to diagram the processes by which nitrogen moved through the system. Then the data from field studies were summarized as an annual budget, that is, the amount transferred along each pathway during 1 year along with the annual loss or increment in each storage compartment. In some cases data were not available from the field site, so literature values were employed under these circumstances (Sollins et al. 1976).

The estimated rate of nitrogen fixation was about eight times the measured nitrogen input by precipitation. Nitrogen losses were a small fraction of the total stand nitrogen dynamics and loss to groundwater amounted to only about 10 percent of the input or roughly the rate of accumulation. Hydrologic input accounted for only 11 percent of the total input; the remainder was due to nitrogen fixation. The only significant hydrologic transport of nitrogen was that from the litter layer to the soil, so the authors (Sollins et al. 1976) caution that conclusions regarding cycling of nitrogen based solely on hydrologic inputs and outputs can be misleading.

The nitrogen losses from this system were quite low, and only slightly greater than those reported for a 37-year-old Douglas-fir ecosystem (Cole et al. 1967). Although live biomass in the H. J. Andrews Experimental Forest watershed old-growth stand was decreasing, the detrital mass was accumulating. Therefore, both these studies supported the hypothesis of Vitousek and Reiners (1975) that losses of limiting elements remain small as long as biomass is accumulating (Sollins et al. 1976).

Coweeta Hydrological Laboratory and Experimental Forest

This 2 185-ha research installation in the Blue Ridge Province of the Appalachian Highlands represents the southeastern deciduous forest with 70 percent of the vegetation composed of oaks (*Quercus* species), hickories (*Carya* species), and red maple (*Acer rubrum*). Elevation in the study watershed ranges from 721 to 977 m with an average slope of 40 percent. Climate is classified as maritime with cool summers, mild winters, and adequate rainfall in all seasons.

The nutrient dynamics of the vegetation on this hardwood watershed can be summarized as below (Day 1974; Day and Monk 1975):

Transfers	Nutrients (kg ha^{-1}) K	Ca	Mg	Na
Input to woody parts	81.7	64.9	15.4	3.8
Output				
From woody parts				
Leaf-fall	.7	6.5	.1	.000 1
From reproductive parts				
Leaf-fall	3.6	1.1	.1	.000 1
From leaves				
Leaf-fall	43.3	35.5	10.7	.3
Leaching	25.8	3.9	2.3	2.3
Herbivores	4.0	4.1	1.1	.03

Leaf-fall represented the greatest nutrient output from the vegetation compartment (56 percent of the K, 69 percent of the Ca, 75 percent of the Mg, and 11 percent of the Na). Leaching was the second largest nutrient output flux from the vegetation and accounted for the largest loss of Na (Best 1971).

Individual species appeared to have different nutrient cycling strategies, such that canopy-sized trees were more important in the long-term nutrient cycle, nutrient rich understory species were more important in the annual cycle, and evergreen species were important in cycles of intermediate lengths because of short-term storage in their perennial leaves. Even though most of the annual nutrient uptake was recycled during the same season (92 percent of the K, 74 percent of the Ca, 93 percent of the Mg, and 68 percent of the Na), the accumulation of nutrients was considerable in this uneven-aged mature hardwood forest. Day (1974) found the nutrient amounts in the above ground parts to be 237.3, 555.4, 49.1, and 47.9 kg ha^{-1} for K, Ca, Mg, and Na, respectively.

Turnover of the nutrient pool in early old field successional stages is rapid and takes from 1 to 3 years since most of the plants are annuals or short-lived perennials. In mature forests, turnover of the vegetation nutrient pool takes much longer because a diversity of cycling strategies exist. Nutrients are stored in the different vegetation components and recycled at time intervals ranging from 1 to several hundred years, depending on the plant component and the species growth habit (Day 1974; Day and Monk 1975).

Central Plains Experimental Range

The site is located on the western edge of the Central Plains and is dominated by short grasses such as blue grama (*Bouteloua gracilis*). The topography is flat to gently rolling, and rainfall is only about 30 cm. The winters are moderately cold, and the summers hot and dry.

This was the field site for the International Biological Program Grassland Biome Pawnee site, and about 80 senior scientists worked here during the period of 1968 through 1974. Elaborate studies measured the response of this grassland ecosystem to various cattle grazing intensities. Four small watershed were enclosed to measure inputs and outputs of nutrients and water. In addition to studies of biomass and species population variables, there were a number of investigations which dealt with specific ecosystem and physiological processes.

The scientist at this site constructed a large, highly linked computer simulation model of this grassland. The model utilized mostly first order differential equations to describe the mechanisms of the ecosystem processes in such a way that predictions could be made about the flow and accumulation of carbon, water, and nutrients. The model, called "ELM" (Ecosystem Level Model), was developed primarily for this site though it has subsequently been adapted for other grassland types. It is capable of predicting the behavior of grasslands under various conditions, such as grazing intensities, additions of nutrients and water, and the occurrence of fire. In addition to the ecosystem level predictions, the model has been particularly useful for generating hypotheses about how the ecosystem works and for asking questions which lead to further experimental studies.

Big Bend National Park

This large National Park is situated on the Rio Grande River in the southwestern United States and includes the entire Chisos Mountain Range. Elevations range from about 500 m to over 2 300 m. The low elevation plains are dominated by the hot desert shrub, creosotebush (*Larrea tridentata*). The high mountain canyons support Arizona cypress (*Cupressus arizonica*), Ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii*). Rainfall ranges from about 15 cm on the desert lowlands to above 50 cm in the highest mesic canyons.

A study which clearly shows the advantage of a long-term research site is being conducted in a high mountain canyon in the Chisos Mountains. Here the Mexican pinyon pine (*Pinus cembroides*) and the evergreen gray oak (*Quercus grisea*) dominate the upper canyon slopes, whereas the deciduous Graves oak (*Quercus gravesii*) is dominant on the mesic lower slopes and canyon floor between the ephemeral streams. By establishing permanent plots in 1964 and then following the seedling population dynamics for the following 9 years, Whitson[2/] has been able to draw several conclusions regarding vegetation population dynamics of these species: (a) younger seedling classes of these tree species experience greater mortality than older classes, (b) Mexican pinyon pine seedlings are apparently more drought tolerant than those of Graves oak, (c) environmental factors following 1964 are favoring Graves oak germination and establishment, suggesting

[2/] Personal communication, Paul D. Whitson, Department of Biology, University of Northern Iowa, Cedar Falls.

that either significantly high germination periods or droughts may cause gaps or spikes in Graves oak age distribution profiles, and (d) the influence of a single drought in the southwestern United States may influence vegetation and species population structure for many decades thereafter.

Comparisons Across Biosphere Reserves

The previously described studies have dealt primarily with one community type in each of five U.S. Biosphere Reserves. It is possible, however, to compare ecosystem properties between community types in these large sites or between the sites themselves. Reichle (1975) compared the energy flow through successive trophic levels (green plant production, animal consumers, and microbial and invertebrate decomposers) in the prairie ecosystem at the Pawnee site on the Central Plains Experimental Range with an eastern deciduous forest at Coweeta Experimental Forest. Using calories per square meter per year scaled to the nearest power of 10, he showed that the forest had a larger standing crop of 10^8 as compared to 10^6 for the grassland. Most of the excess biomass in the forest was of woody supportive structures. The forest had a slightly higher annual net primary production, but the energy flow through the various trophic levels was similar in both systems. Both plant respiration and animal consumption values were remarkably close, even though large herbivores are more characteristic of the grassland. A large amount of energy (10^7 in the forest, 10^6 in the grassland) flowed through the decomposer organisms. This energy flux through the decomposers represented a relatively new appreciation of ecosystem dynamics, and its generality can only be tested by examining a number of different types of sites.

As noted previously in conditions where runoff is appreciable, considerable information about watershed mineral cycles is provided by observing element concentrations in stream flow (Reichle, 1975). The contrast of stream discharge values from different ecosystems in the same general geographic area may reflect how efficiently each type of ecosystem recycles nutrients. In comparing four vegetation types on the Coweeta site, Johnson and Swank (1973) showed that the grass-herbaceous ecosystem, which does not have the temporary storage capacity in woody structural material, was the least frugal in its utilization of nutrients. The coppice ecosystem, characterized by a dense stump-sprout regrowth of a clearcut forest, has a well developed root network and rapid growth rate and was very efficient in its uptake and recycling of nutrients. The White pine (*Pinus strobus*) ecosystem lost somewhat lesser amounts of nutrients than the mature hardwoods (Reichle 1975).

The nutrient budgets of the three forest Biosphere Reserves can be compared by using data summarized by Reichle (1975). The net loss of calcium, magnesium, and potassium from undisturbed watersheds at Coweeta, Hubbard Brook, and H. J. Andrews is given on the following page:

Watershed	Nutrient (net loss, kg ha^{-1})		
	Ca^{++}	Mg^{++}	K^{+}
Coweeta	0.7	1.9	2.0
Hubbard Brook	8.0	1.8	.1
H. J. Andrews	47.0	12.0	1.5

The Coweeta Watershed is on Precambrian amorphous geological materials, the Hubbard Brook has a granitic substratum, and the H. J. Andrews is underlain entirely by rocks of volcanic origin. Therefore, geology, soils, topography, climate, and vegetation are all involved with the interpretation of these nutrient budgets and, more generally, in the control of the structure and function of ecosystems. Ultimately, the behavior of these ecological systems can only be evaluated in the context of an array of sites like those represented in the Biosphere Reserves.

CONCLUSIONS

In the beginning of this paper, eight characteristics of a comprehensive network of ecological research sites were presented. Then, selected studies from five Biosphere Reserves illustrated these characteristics. Although there are some gaps in the present U.S. Biosphere Reserve coverage, it is clear that widely divergent systems like the moist coniferous forests of the H. J. Andrews Experimental Forest and the dry shrub deserts of Big Bend National Park will help insure that adequate systems will be available for future research. The comparison of nutrient budgets from the three forest Reserves showed the potentiality for testing generalities. Both the nutrient studies of Hubbard Brook Experimental Forest and the vegetation study at Big Bend National Park indicated the necessity of long-term records. The construction of a large ecosystem level simulation model, with the Central Plains Experimental Range as the focal point, demonstrated the role of a common site as aiding the communication between scientists of different disciplines. Finally, each site, with the associated research teams, has generated intellectual conditions which enhance the ecological research of the scientists, both individually and collectively.

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Exploration of the Concept of Marine Biosphere Reserves: What Could be Done and How

by

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INTRODUCTION

The Biosphere Reserve concept has been evolved largely for terrestrial areas, with some attention being given to the coastal zone, and almost none to the sea itself. The concept calls for core areas for baseline research and monitoring and buffer zones to protect the core and for use in studying the effects of human activities. Matched experimental areas can also serve the latter purpose. Thus, the Biosphere Reserve concept is an enlargement of traditional conservation objectives; it highlights research and monitoring, fosters preservation of habitats and ecosystems and the genetic material they contain, and provides for education and training. Applying the Biosphere Reserve concept to the sea remains a very great problem. In this paper I will examine this problem in very broad terms.

Several central questions are important: (a) how may the functional units, or ecosystems, of the sea be identified?; (b) how may core areas, or what may be called critical habitats, be described and protected?; (c) how may we learn to recognize buffer areas, those places where essential processes for the stability of the core take place?; and (d) what research plans and methods are appropriate, especially emphasizing process studies? These are very large questions. Some answers are at hand for terrestrial and some coastal areas, but very few for the vast hydrospace we call the sea. Nevertheless, it is fortunate that the U.S. and U.S.S.R. are united across one area, Beringea where, perhaps, these questions may be productively examined. This area is now mostly sea, comprising the Bering and the Chukchi seas. Not very long ago, it was mostly land, forming a terrestrial migration route between the Nearctic and Paleartic Realms. It is an area of common resources and common native peoples and languages. It is, however, under a complex of national and international jurisdictions, even being a "commons" in many of its aspects.

To attempt answers to the above questions is somewhat presumptious but for heuristic purposes, let us suppose that the functional unit is Beringean Shelf itself. There is some good evidence for this assumption. Hood and Kelly, eds. (1974) and Takenouti and Hood, eds. (1974) present summations of knowledge about the southern portion of the region, about which most is known. The questions related to core areas and buffer zones can only be answered cursorily in light of present knowledge, but certain areas of interest are examined

below in the perspective of the Biosphere Reserve concept. The fourth question must be answered taking into account the great difficulties of logistics in seasonally ice-covered seas. These are the only seas for which neither of our nations, to the best of my knowledge, has all-season oceanographic ships. Thus, at-sea research and ground truth for aerial or other methods is a very real problem.

Two major considerations loom at the outset. First, the "commons" and various jurisdictional regimes for the sea raise difficulties. The Law of the Sea, as currently defined, is not in accord with ecological reality, nor do mechanisms exist for the creation of reserves in international waters. Hedberg (1976) states, in considering newly proposed 200-nmi (360.4-km) limits, that such reserves "lack any basis in nature and logic." Hedberg considers petroleum resources in making his statement; but for living resources, such limits are even less sound ecologically than they are for minerals. He proposes, for example, a "continental margin boundary guide," in which case there would be no boundary between our nations, which might be a useful outcome of the "marine revolution" (Ray 1970). Of course, the point here is not to examine marine law, but to comment on the present impossibility of unilaterally setting aside representative samples of ecosystems and biotic provinces outside territorial waters. This does not mean that we should not establish Biosphere Reserves there, only that we must do it jointly, paying perhaps lesser attention to core and buffer boundaries than to the compatible and sustainable impacts of our activities.

The second consideration has lately been expressed for MAB by Dolan, Hayden, and Heywood (1975). Legally, and in the minds of many, the oceans' high water mark is most often a boundary between two systems. The reverse, however, is true; this line unites the two realms because of the dependency of both oceanic and terrestrial organisms on the coastal zone. The coastal zone, in both aquatic and terrestrial aspects, is a transitional zone, or ecotone, and comprises some of the most dynamic physical and biological environments. An analysis of the coastal zone involves recognition of aquatic and terrestrial physical and biological processes. It may be said, with considerable justification, that all of Beringea is a coastal zone, particularly if we take Pleistocene history into account.

Ray and Dasmann (1976) have recommended an approach to the establishment of Biosphere Reserves in marine environments. Acknowledging our ignorance of the sea, we state "...we must not await the accumulation of complete knowledge - an impossibility anyway - before taking significant action." We point out essential differences between terrestrial environments and those of the sea, among which are the size of the ecosystems, the mobility of marine organisms, the three-dimensionality of the hydrosphere, and "sink," "downstream," and "short circuit" effects. We point to habitats as being reflective of ecological processes and conclude: "given that we do not understand ecological processes well enough to be able to predict the effects of man's perturbations; given our desire to protect the integrity of nature; given that marine and estuarine systems are too large to protect by means of reserves in their entirety; given that

the existence of a diversity of biotic provinces, habitats, species, and cultures of man, is probably reflective of ecosystem processes in all their complexity; therefore, let us set about assuring that diversity in all its aspects is represented in protected areas for the principal reason of understanding those processes and formulating [illegible] for man's actions which will neither jeopardize them nor - in the long run - man himself."

I can think of no area more appropriate to this objective than Beringea.

DESCRIPTION

Beringea is shown in figure 1 and consists of the shelf area of the Bering and Chukchi Seas, bordered on the north by the Arctic Ocean Basin and on the south by the deeper waters of the southwestern Bering Sea which forms in most ways, a northward extension of the Pacific Ocean.

First and foremost, the area is immensely productive and rich in terms of both renewable and non-renewable resources. It is essential that resources be exploited compatibly, and particularly that non-renewable resources not be exploited so as to jeopardize the renewable ones. I cannot think how the reverse could take place. But the immediate, short-term gain from exploitation of oil and gas, for instance, is so immense that one can quickly lose sight of the fact that fisheries and other living resources are more valuable in the long run, as they are theoretically infinite, given time. Nevertheless, conflicts have arisen and will intensify. Figure 2 illustrates one such conflict and also presents a strong justification for the establishment of Biosphere Reserves in the region as a matter of highest priority.

The Beringean region is at times temperate and at times arctic; this factor is essential in comprehension of it. Sea ice cover, shown in figure 3, actually increases total annual production because its presence is a major factor in two primary productivity periods--late winter to early spring and late spring to early summer. McRoy and Goering (1971) have summarized information on the mechanisms involved. Winter primary productivity derives both from algae which live on and in the sea ice and from the water column, meaning that winter production is high in contrast to many oceanic regions. Summer primary productivity rates are among the highest of any ocean, those of the Bering Strait region rivaling oceanic upwelling systems. New calculations tell us that sub-ice algae contribute about 9 percent of total Bering Sea annual primary production, but this figure is somewhat deceptive as there is a significant contribution from the presence of sea ice itself. The algal bloom in the ice is but part of the picture. There is also a bloom in the wake of the retreating spring and summer sea ice which "is apparently promoted by stratification of the water column from melting ice." McRoy and Goering further state: "Because of the seasonal ice cover the total annual production of the Bering Sea is considerably enhanced. Furthermore, the annual spring increase begins in the middle and northern waters instead of the usual southern."

Figure 1.—Beringea and its proposed Biosphere Reserves.

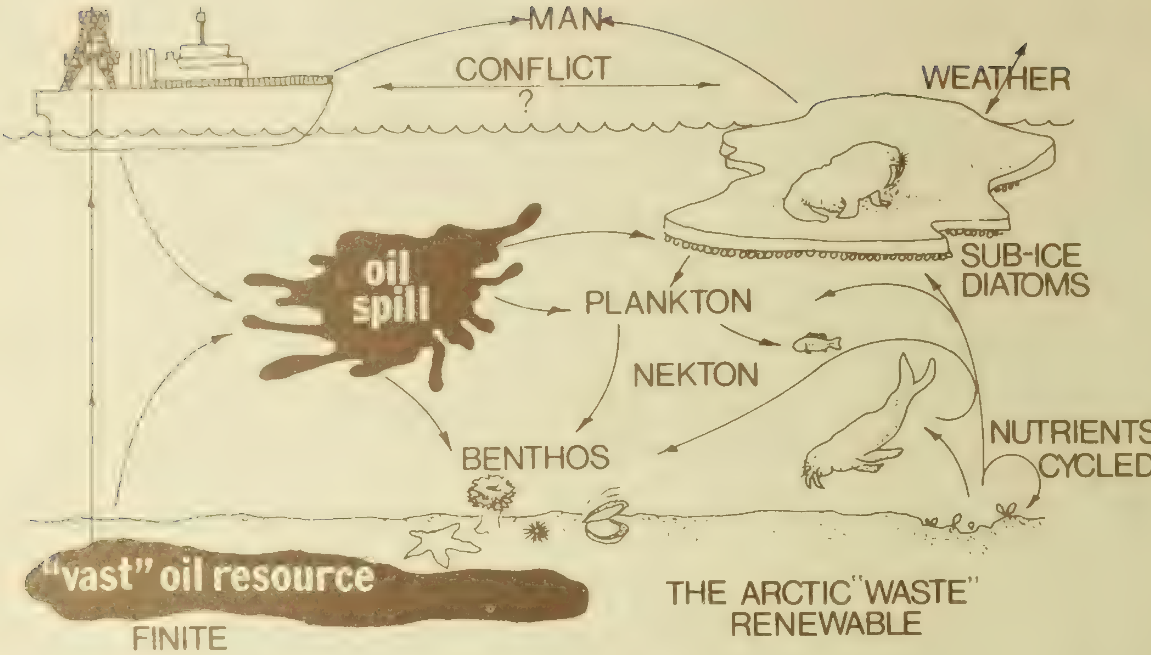

Figure 2.—Potential conflicts which may arise from man's requirements for the living and non-living resources of Beringea. The popular conception of an Arctic "wasteland" ignores the huge living resource of the region and the fact that it is renewable. Oil threatens benthic fauna, subice diatoms, plankton, and the integrity of sea ice and its role as a determinant of northern climate. (After C. G. Ray and D. Wartzok 1974.)

Two other major sources, rivers and lagoons, contribute to total production. The flow volume from rivers in the U.S.S.R. is about 104 km^3 annually, or about 25 percent of the total. Alaskan rivers, particularly the Yukon and Kuskokwim, contribute about 308 km^3. Rivers bring in sediment, nutrients, and certain pollutants, the latter so far in relatively small amounts. Lagoons are the other major source. Their tidal exchange rates are equivalent to major rivers; and one of them, Izembek on the Alaska Peninsula, is perhaps the largest eelgrass (*Zostera*) bed in the world and may contribute 10 percent of the total flow from all lagoons of the Bering Sea (McRoy and Goering, 1974). Its annual production is 3 x 10^5 metric tons of vegetation, perhaps a third of which is transported to the sea, or 1 x 10^5 metric tons, meaning that the total contribution from all lagoons to the Bering Sea is 1 x 10^6 metric tons. Barsdate, Nebert, and McRoy (1974) state that Izembek's annual production is: 16 600 metric tons (t) in particulate carbon, as organic matter important in the detritus cycle; 7 400 t nitrogen; 1 660 t phosphorus; 3.45 t copper; and 386 t silicon. It is quite obvious from these figures that riverine and lagoon habitats are prime sites for the creation of Biosphere Reserves. A good part of the nutrition of the region depends on them.

Ice is also implicated in the ecology of marine mammals and birds which are so dominant in Beringea. Far from impeding the distribution of marine mammals, sea ice aids some of them. Fay (1974) notes that

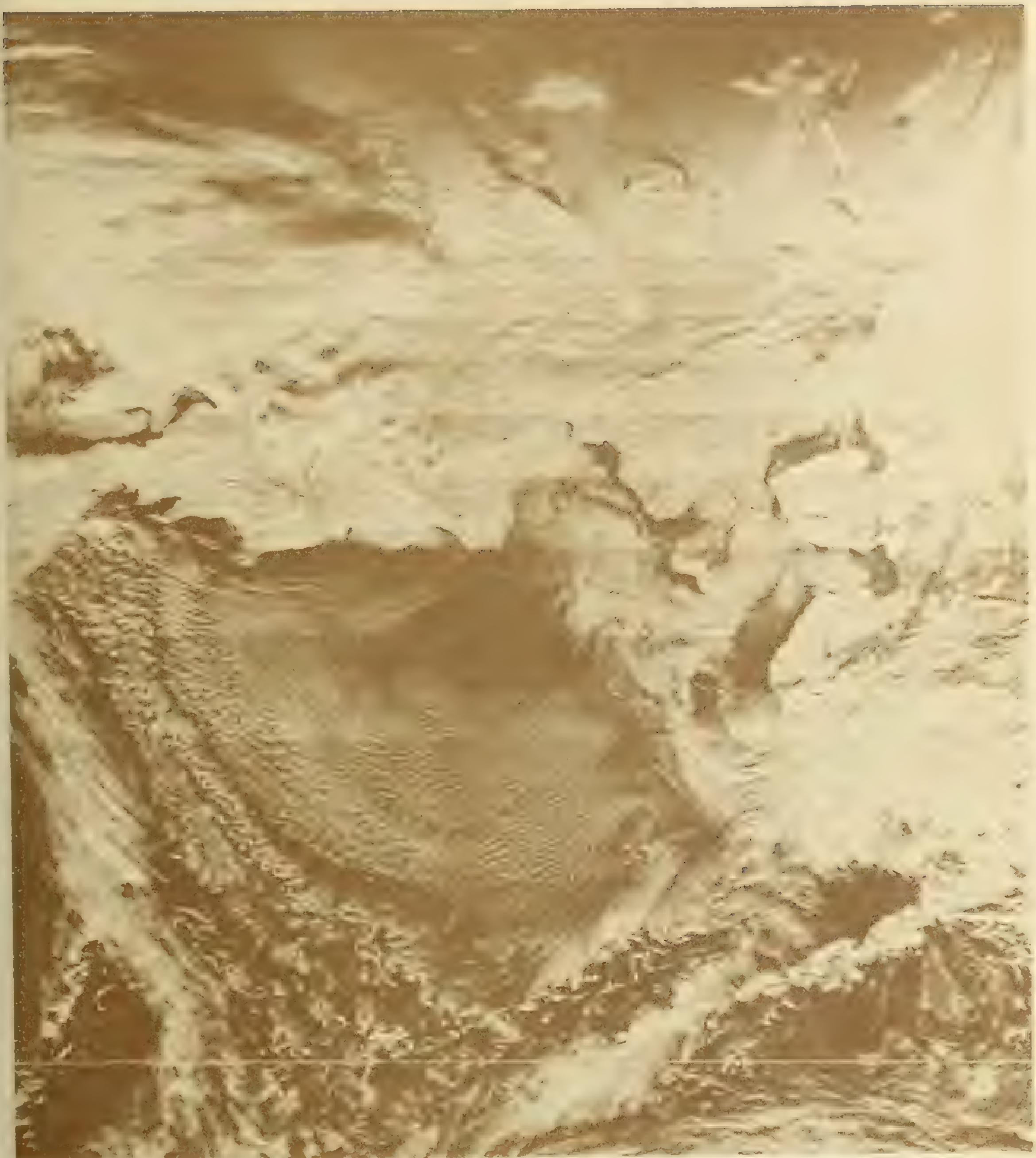

Figure 3.—Satellite photograph of Beringea—13 February 1973.

sea ice provides marine mammals substrate for rest and to bear young. The need to find access to water dominates their lives and is a major reason why birds are not found among winter sea ice to the extent that some marine mammals are (birds are not able to make holes in sea ice for access to water). Hood, ed. (1974) notes that there are 25 marine mammals species found in Beringea, most of them part-time. Prorating them for the Bering Sea in terms of full-time residents only, there are about 1.5 million individuals, comprising 450 000 t. They may consume 9-10 million t nekton, plankton, and benthic organisms annually. This is about a million t in the form of carbon. The walrus is an example for which more precise estimates of annual consumption are possible than for other species. Based on: (1) a total Bering Sea primary production of 274 million t of carbon; (2) a minimum population of about 125,000 walrus, and a 5 percent of body weight daily food requirement; and (3) a 27-percent conversion rate between trophic levels, it may be calculated that walrus require about 1.1 percent of all the carbon available to all primary carnivores. Evidently, walruses require about 220 000 t carbon, or a fifth of the total required by all marine mammals of the Bering Sea. Hardly any of these mammals, not even walruses, are primary consumers, for all or part of the time. Secondary consumers need four times as much carbon in terms of primary productivity, so that the total requirement of all marine mammals could be as much as 20 percent of the total carbon available to consumers.

Birds and fishes are also exceedingly numerous in the region. The Bering Sea supports one of the world's greatest fisheries. When all of these requirements are considered together, the immediate need is to clarify the very tentative figures on utilization and to achieve a predictive basis for measurement, for there is a clear conflict between man's fisheries and the needs of marine mammals for sustenance. Maximum yield to man's fisheries will surely impinge on marine mammal food availability, and perhaps already has in the case of the fur seal's (*Callorhinus ursinus*) lowered recruitment rates (Ray and Norris 1972). The point here is that one cannot achieve both maximum yields of fishes and maximum yields or even maximum protection of marine mammals and birds at the same time. Regional management, or ecosystem management, is required; and this will in turn require regional research and monitoring.

Turning to non-living resources, Hedberg (1976) points to the great non-renewable resource of the region, petroleum. Among the conditions conducive to its presence are a rich source of the right kinds of organic matter, adequate blanketing of sediments (1 000 m or more in depth , and proper accumulation traps. These conditions are met very often on continental margins; many offshore fields are now located on such uplifted margins. The Beringean region has very thick sediments, to 10 km for the Bering Sea and to 6 km for the Chukchi Sea, and the potential for petroleum exploitation is excelle

On the other side of the coin, Campbell and Martin (1973) have pointed to the great hazards involved in oil spills under sea ice. Only a slight reduction in albedo, which occurs when oil works its way to the ice surface, causes a significant reduction in ice equilibrium thickness. A 20-percent reduction in albedo can cause

thick Arctic sea ice to disappear in 2 years. Three dispersal mechanisms spread oil about, under, and among sea ice--lead-matrix pumping, oiled hummuck melting, and under-ice transport in the form of oil-water emulsions. Therefore, oil disperses widely, at the same time being degraded very slowly and being practically inaccessible to cleanup in these environments. Campbell and Martin did not consider biological effects; but for primary productivity and for such animals which use sea ice for hauling out, the implications of a spill appear obvious.

AREAS

It is widely acknowledged that a classification scheme forms one basis for the inclusiveness of a reserve system. In this case, there are two such applicable schemes, that of Uvardy (1975) for terrestrial systems and that of Ray (1975) for coastal and marine systems. Beringea is bordered, according to Uvardy, by Alaskan Tundra of the Nearctic Realm and by High Arctic Tundra and Low Arctic Tundra of the Palearctic Realm. My scheme is tripartite. I first place Beringea within two zoogeographic regions: the Temperate North Pacific/Boreal-Arctic for the Bering Sea and the Polar Arctic for the Chukchi Sea. Second, in an attempt to classify coastal regions, I have followed wide practice in identifying Beringea within the Pacific Subarctic-Arctic Biotic Province with Ice-Stressed Coasts. The third part of the scheme is habitat classification, and there are several habitats from exposed to protected, to lagoons and estuaries, to sea ice and water bodies, and to the benthos. Obviously a great deal of modification and study will be required to give these schemes workability of unity of approach, as well as credibility in terms of uniting land-and-sea coastal ecotones.

The areas of interest described below are not meant to be inclusive, nor do they describe ecosystems. Rather, they are "hot spots" for our activities, places where great productivity occurs, places from which nutrition important for the Beringean region emanates, places where conflict is occurring or will occur and where monitoring is especially important, or places where man's history in the region may be recorded in terms of underwater archeological sites. All are identified in figure 1.

The sites may be broken down according to type, but I prefer not to do so at present as some of them serve multiple purposes. They are, approximately from south to north:

1. *Aleutian Islands.* To my knowledge, this is the only Biosphere Reserve proposed for the region. It is an island site and not really a part of Beringea, but forms an important interface with the North Pacific.

2. *Kommandorskii Islands.* As the place discovered by Bering and where the last Steller Sea Cows existed, this site has both historical and biological interest. It is an Aleutian extension, geologically, and is not a part of Beringea, but supports a large herd of Northern Fur Seals, *Callorhinus*, which interact with those of the Pribilofs, so it should be considered.

3. *Pribilof Islands - St. George Basin.* This area supports the largest Northern Sea Lion herd in existence as well as being a major fisheries region. It has petroleum potential. Its waters may contain archeological material.

4. *Izembek Lagoon.* The value of this lagoon is given above.

5. *Northern Bristol Bay.* This is an area of intense fisheries interest. It includes the drainage from several important rivers which are spawning grounds for important commercial and non-commercial fishes. Its primary productivity may be very high, but it has a rather low standing stock of benthic organisms, possibly because of predation effects.

6. *Kuskokwim Delta.* The value for production has been discussed above. In addition, the delta supports vast waterfowl breeding grounds.

7. *Nunivak Island.* There may be archeological remains in its nearshore or offshore waters.

8. *Yukon Delta.* The same may be said for this area as for the Kuskokwim.

9. *St. Matthew Island.* The area is a possible archeological site.

10. *St. Lawrence Island.* Many archeological sites exist on land. There may be some underwater as well.

11. *Anadyr Delta.* This is the third largest river emptying into Beringea and contributes valuable nutrients.

12. *Chirikov Basin.* South of St. Lawrence, the benthic standing stock is 100-200 gm/m^2 in wet weight. North of St. Lawrence, the figure jumps to 1 000 gm/m^2. The explanation may lie in Yukon-Kuskokwim-Anadyr contributions in nutrients which flow north to the Chirikov Basin. This is an important feeding area for many marine mammals, including summer populations of the grey whale (*Eschrichtius robustus*).

13. *South Central Chukchi Basin.* The benthic standing stock is even higher here, to 1 000-3 000 gm/m^2 wet weight. This is probably because of a "river mouth effect"; that is, nutrients and particulate matter fall out of the water column as water current velocities decrease north of the Bering Strait. It is inherent that the Bering Strait itself be considered in studying this region. The region is to date almost unexploited and supports the bulk of summer grey whales. It has very high petroleum potential.

14. *Shishmaref Lagoons.* These are not nearly as well known as Izembek; but by analogy, we can estimate their importance to the region.

15. *Wrangel Island.* The entire island is important but is particularly so for marine animals and birds. The most important walrus summer hauling out ground in the Chukchi Sea occurs there on Cape Blossom. The surrounding region is very productive as well. These are but brief sketches, each of which deserves a paper in itself.

They are only a first attempt to suggest Biosphere Reserves for Beringea. Want of knowledge of the U.S.S.R. side has impeded my efforts somewhat.

RESEARCH AND MONITORING

Research and monitoring are really two aspects of the same thing; the essential difference being that research seeks to identify essential key data and processes and to form stochastic models to be used as bases for long-term guardianship, which we may call monitoring and by means of which we may keep a watch on our own perturbations. In the case of Beringea, critical problems and conflicts are arising so rapidly that protection, research, and monitoring must evolve together. I can give only the broadest outline here, based in large part on the difficult logistics problems mentioned above.

There are three kinds of surface-based logistics which come to mind:

1. Land Stations. Several sites exist where data may be gathered from shore. These may not include laboratories at present, but the sites could easily be so amplified. Many native villages exist, for example, where scientists have worked on population or environmental problems.

2. Ships. A ship might be assigned as a long-term commitment to MAB. In fact, there is little alternative to ship-based activities for many of the sites listed above.

3. Remote Stations. Modern technology has given us many ways to look at the environment and to quantify what we often cannot see; side-looking radar is one, radio tracking of living organisms is another. Movements of ice and its structure and the movements of marine mammals or birds, for example, may be recorded without man's attendance and the data either stored or transmitted in real time to data-collection sites via satellites.

Obviously, none of these technologies give the sort of coverage and resolution we need over the ice where few, if any, ships venture on any but a very short-term basis. Remote sensing is the only alternative available:

1. *Visual surveys.* These have been conducted by both of our countries lately in conjunction with the Marine Mammal Project of the U.S.-U.S.S.R. on cooperation in the field of environmental protection. Visual or strictly observation surveys have major faults in terms of quantification, but they are useful for descriptions of biotic distribution and some superficial descriptions of biota and habitat.

2. *Aircraft remote sensing.* Aircraft such as NASA's Convair-990 and its NP-3, as well as those of the U.S. Geological survey, have been flying over Beringea since 1973 taking part in BESEX, the U.S.S.R.-U.S. Bering Sea Experiment, AIDJEX, the Arctic Ice Dynamics Joint Experiment, BESMEX, The Bering Sea Marine Mammal Experiment, and projects of the Outer Continental Shelf Energy Program. I am not sufficiently aware of Soviet activities in remote sensing to mention them. Radar, laser profilometry, microwave imagery, infrared imagery, and visual spectrum photography are now developed to the extent that quantification and description of habitats and certain biota within them are possible in ways that visual methods cannot match. Ground truth for these methods, however, remains a problem because of the inaccessability of many areas.

3. *Satellite remote sensing.* In no other way is such a broad environmental perspective possible. Figure 3 shows Beringea in mid-winter 1973. Resolution obtained by satellite methods is on the order of 30 - 1 000 m, according to which satellite and which spectra are being used. Ground truth is a problem, as for other remote sensing methods. I have so far mentioned only logistics. Objectives for research include:

a. Habitat description;
b. Dynamics of river and lagoon effluent;
c. Ocean dynamics;
d. Food web and trophic analysis;
e. Assessment and population studies;
f. Effects of man's harvest on the ecosystem;
g. Pollution;
h. Physical effects of exploitation;
i. Effects of "civilization" on traditional cultures; and
j. Adaptation, physiology, and behavior of selected "target," "sentinel," or "keystone" organisms.

These 10 are hardly inclusive; nor perhaps should they be. It is important that research in Biosphere Reserves be highly selective, emphasizing process, target species, and target questions. It is not necessary to incorporate all phases of research, but it is important to identify research according to well-worked-out theoretical process models or stochastic models derived from known data.

I would like to select one example of the sort of thing I have in mind, namely BESEX, The Joint U.S.S.R. and U.S. Bering Sea Experiment. Its structure was worked out by means of working groups and/or task forces. A large scale, joint expedition resulted in 1973, involving ships and planes of both our nations. A symposium followed (Kondratyev, et al., eds. 1975) in which data were presented in detail only a year following the experiment. BESEX forms a model for us, and I dare say, for other activities of MAB and the U.S.-U.S.S.R. Agreement on Cooperation in the Field of Environmental Protection.

CONCLUSION

I propose that we take the BESEX approach in evolving marine and coastal programs for Beringea. The immediate problem is to compose a Task Force to define the program in detail; that is, to first identify Biosphere Reserve areas and logistics for the work and to evolve suitable methods directed towards a high-priority list of target questions. This must be a long-range program; but it should have regular review, perhaps annual, for continual data-exchange and reexamination of objectives. It must be flexible while being concrete and pragmatic.

Second, the legal and jurisdictional aspects of Biosphere Reserve establishment for the coasts and seas must be examined. The Task Force must look into this as a matter of some urgency. There need not be the implication that such reserves eliminate man's activities over wide ocean space, but that certain core areas of limited size be so exempted and that man's activities throughout be in accord with the Reserve's stability, to the best of our ability to set guidelines. This involves the evolution of a preliminary management plan based on present knowledge.

Third, we need to develop a habitat classification scheme for Beringea so that representative habitat types may be included in Biosphere Reserves. Existing schemes for land, coasts, and seas are not ecologically compatible. Perhaps satellites, with an adequate "ground truth" program, can help in this large task.

Fourth, we must not omit research and monitoring of animal populations and I strongly suggest using birds and mammals as indicator species as they appear above the air/sea interface and can be remotely sensed, visually or otherwise. Remote sensing, however, gives only part of the picture. Radio tracking is the only present technology for monitoring individuals and/or populations semi-continuously. Strategic positioning of land stations for tracking radio-tagged animals could be of immense benefit. The technology for this is rapidly becoming available.

Fifth, native groups must be involved in this work. Beringea is united by common cultures which are themselves threatened and which have been effected severely by civilization over the past 200 years. We cannot reverse matters, but we can seek involvement of natives for the purpose of determining wants, needs, and values.

What I have suggested is ambitious in the extreme, but I see no other way to handle this subject. We cannot delude ourselves that by setting limited areas of sea aside we protect ecosystems, nor that our knowledge is better than marginal. Beringea itself is, in a large sense, a Biosphere Reserve candidate in its own right. We must see our chore as identifying core areas within it for specific, local protection and study which relates to the whole. Sullivan and Shaffer (1975) note that the "strategy for locating... reserves involves consideration of their location, number, size, and linkage. The equilibrium theory of island biogeography is a useful analytical tool for predicting future biogeographies

according to the dynamics of present plant and animal distributions." Thus, we seek not to locate or create islands within Beringea which cannot remain diverse or stable, but to see where the linkages are and, by protecting them, protect the region as a whole while we use and enjoy it.

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The Role of Biosphere Reserves in the Management of National and International Ecosystems

by

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INTRODUCTION

Although all periods of history are unique and interesting for various reasons, the present period is especially interesting because of the apparent conflict between environmental concerns and developmental needs. The past decade has witnessed a growing awareness of the need for and desirability of clean air and water, of energy development and conservation, of soil productivity and maintenance, of population stabilization, and of wildlife conservation and habitat protection. At the same time, we have demanded continuing supplies of inexpensive energy, increased industrialization, more money, and more mobility. At first, we wondered if industrialization and environmental integrity were even possible; perhaps one had to be sacrificed for the other. We now recognize that both are possible, and necessary.

ECOSYSTEM MONITORING

The need to monitor and document the changes in national and international ecosystems which will occur in the resolution of the present development-environmental conflict is of increasing importance. Biosphere Reserves represent a new and unique method of responding to this need. Such reserves are necessary not only in preserving or protecting natural areas and associated genetic material, but also as centers for scientific research and educational programs. It is extremely important that such Biosphere Reserves encompass all major ecosystem types, whether national or international in scope, and whether pristine or man-influenced. Only from such a diversity of areas can accurate monitoring of all environmental impacts be accomplished.

Biosphere Reserves are located throughout the world and can generally be described as land, coastal, or aquatic environments or ecosystems which contain representative examples of natural biomes or habitats which are protected so that they can be maintained for future generations. While this is a description of what they are, the question remains, what do they do? What is their role in the management of national and international ecosystems?

THE ROLE OF BIOSPHERE RESERVES

In my judgment, Biosphere Reserves should have four basic roles. First, they should be an integrated part of an interdisciplinary, worldwide program. Even though under the protection and control of a sovereign State, the reserve should not be maintained for the exclusive use of scientists from the sponsoring State. Nor should the reserve be dedicated to the study of only one factor of the environment. The Biosphere Reserves should be parts of a whole, parts of an entire and cohesive system, where individual but coordinated conservation and research activities by international scientists from all disciplines of environmental science can proceed. Biosphere Reserves will also serve as genetic pools designed to preserve the diversity of plants and animals essential to the preservation of life support systems.

The second basic role of Biosphere Reserves is to provide baseline data for measuring intrusions into the environment. Although it is certainly admirable to study ecological relationships and measure environmental impacts, such data have little meaning without knowledge of the original relationships or the undisturbed environment. Once these baselines have been determined and recorded, it is possible to assess present environmental conditions and predict with greater accuracy the probable environmental consequences of resource decisions or habitat manipulations.

The third role is to use the Biosphere Reserves as a platform for the development of an international monitoring system similar in design philosophy to that suggested by the Global Environmental Monitoring System (GEMS). Although the environmental monitoring program envisioned for the Biosphere Reserves is more comprehensive than that suggested for GEMS, the program parts are similar and include monitoring, research, evaluation, and information exchange. These steps are essential in the establishment of a practical and efficient system. The GEMS system also calls for the establishment of data banks at national, regional, and world levels. Such data banks would also seem valuable and worthwhile for the Biosphere Reserve monitoring system. The Biosphere Reserves should provide a coherent, integrated source of baseline data and information for determining long-term trends and environmental impacts. National facilities could concentrate on the analysis of data collected as part of the reserves monitoring programs. The regional facilities could analyze and store data concerning environmental changes of regional or multi-biome concern. The world facility could assess world environmental conditions, develop reports and reference materials, and provide a location for training and education programs.

The final basic role of Biosphere Reserves is to monitor changes in the global environment. This function could be handled in large part under the world facility just described. It would be the responsibility of individual reserves to monitor environmental conditions in a coordinated and integrated manner so that comparable data are available globally. Only in this manner can similar biomes

and ecosystems in different parts of the world be monitored and compared in a comprehensive and meaningful fashion.

MONITORING BIOSPHERE RESERVES

In this regard, I would like to describe an environmental monitoring system implemented by my organization, the National Wildlife Federation. The National Wildlife Federation's Environmental Quality (EQ) Index is an effort designed to provide the concerned citizen with a comprehensive review of published information on factors affecting environmental quality presented in rather simple language and graphics readily understood by the masses. We are not so foolish or short-sighted as to think that our Index represents the ultimate product or even the best analysis of available data. We do feel, however, that it gives the average citizen a much better grasp of the environmental situation as it exists today and as it might look tomorrow, next year, and in the foreseeable future.

The EQ Index is the end product of an exhaustive, scholarly exercise that attempts to reduce reams of information--much of it disjointed, at best, and some possibly erroneous at worst--into a simple, orderly, graphical representation of environmental conditions. When first published in the fall of 1969, six natural resources were evaluated in the EQ Index: air, water, soil, forests, wildlife, and minerals. In 1970, a seventh item--living space--was added to the list. These categories of the environment were subjectively rated from Best to Worst on a scale of 0 to 100. An "0" would equal death or disaster; "100" would be ideal conditions with environmental equilibrium. For example, soil is, in our relative judgment, in the best condition of any single resource; but soil conditions are still far less than ideal. In 1970, it was given an Index of 80, but this year, because of continuing losses, the rating slipped to 73. Air represents the worst category of the environment. It actually poses a danger to human health in many cities. The 1970 Index was placed at 35, fell to 33 in 1972, but has improved in 1975 to be rated at 35.

Quite obviously, a number of value judgments were arbitrarily made. These, in turn, lead to the conclusions presented in the EQ Index. Our judgments and conclusions are necessarily subjective; and while we consider these judgments scrupulously fair, they are subject to challenge. We believe that with experience and additional data, they will become more accurate. In fact, we hope the scientific community, possibly through a Biosphere Reserve monitoring system, can help in eliminating those judgments which have insufficient backup data by filling in the gaps in our body of knowledge about the biosphere in which we live.

SUMMARY

The scientific community has an obligation to assist our decision-makers in choosing between a denaturalized, defiled, and debased

existence or a new birth of quality living complete with the preservation of objects of great natural beauty and esthetic appeal in addition to the restitution and rehabilitation of those renewable natural resources upon which life is dependent. There are those who say science, in an ever growing industrialized, mechanized, and computerized society, is incapable of providing the technology to clean up our polluted planet. I say the capability is there but the willingness to devote the time, to pay the price, to establish objective standards of enquiry, to identify pollution abatement as a high priority domestic and world problem is lacking. The Biosphere Reserve program is a good first step in the right direction and will become symbolic of the determination of world leaders to know more of the effects of man's intrusion into the environment.

The professional resource manager should immediately embrace an advocacy role in environmental affairs. The scientist should no longer be content with publishing the methods and conclusions of a research effort or handling his working assignment. In this modern day of better education and an ever expanding body of knowledge, the cool, calculated, objective, and expert voice of the true scientist is badly needed in molding international public opinion in the proper form and in formulating guidelines that will direct our international policy toward an improved natural environment and a quality life style for all the people of the world.

Management of Experimental Reserves and Their Relation to Conservation Reserves: The Biosphere Reserve Cluster

by

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INTRODUCTION

The goals and objectives of an international network of Biosphere Reserves [UNESCO[3] Program on Man and the Biosphere (MAB), Project No. 8] are diverse. Major themes include (1) the conservation of representative and unique environments, (2) research emphasizing environmental monitoring under natural conditions, (3) research exploring the impact of anthropogenic factors on natural ecosystems, and (4) education. Historically in North America, most individual reserves have been established with only a subset of these goals in mind. With existing institutions and a great diversity of ownership patterns, program objectives, and site histories, a single reserve rarely provides the facilities and resources necessary to address all the aforementioned goals.

A major conflict at single-purpose reserves is the frequent incompatibility between the conservation and manipulative research objectives of the MAB program. Hence, protected core areas and peripheral buffer zones were proposed (MAB Task Force 1974) to resolve the conflict between different types of reserve utilization. These zones were drawn as being contiguous in space (fig. 1a). Because contiguous buffer zones available for manipulative studies do not occur around all conservation reserves, an extension of this concept, called the Biosphere Reserve Cluster (fig. 1b), was proposed for the United States by a committee of Federal agencies. Here, the research on human

[1]Research sponsored by Union Carbide Corporation under contract with the Energy Research and Development Administration.

[2]Publication No. 856, Environmental Sciences Division, ORNL.

[3]United Nations Educational, Scientific, and Cultural Organization.

Figure 1. (a) Generalized Biosphere Reserve showing the core and buffer zone concept as suggested by MAB (1974). No development is permitted in the core area, and uses are strictly controlled. Buffer zones are used for research and education purposes, and public use is limited. Manipulations could be carried out in buffer zones, most appropriately in buffer zone 2. (b) Diagrammatic representation of a Biosphere Reserve Cluster. Core-buffer zone concept is extended to include geographically separate reserves which can provide the opportunity for controlled manipulations while also better representing regional variability. Contiguous buffer zone may or may not be present. Fringe areas are shown between and surrounding the reserves.

impacts proposed by the MAB committee for the buffer zone would frequently be conducted at separate but nearby experimental reserves which occur frequently within all the major biomes in the U.S. In this concept, a central conservation reserve forms the core of the Biosphere Reserve Cluster, with a contiguous buffer zone (where available) and with nearby experimental reserves fulfilling the manipulation research objectives. Thus, the cluster of reserves, together with fringe areas needed for future or supplementary studies, can fully address the goals of a Biosphere Reserve network and at the same time can remain compatible with the existing land-use patterns and agency responsibilities.

RESERVE TYPES AND INTER-RESERVE COMPARABILITY

Conservation-Oriented Reserves

Most conservation reserves have been established to preserve unique landscapes and biota. Another major purpose is recreation. Research programs carried out in conservation reserves are usually directed towards the study of natural phenomena, including biological inventories, habitat descriptions, and monitoring of background

conditions in pristine environments. Although investigations of man's impact on the natural environment are carried out in these reserves, they are primarily related to the effects of public use (i.e., recreational development). Manipulations necessary to study more severe environmental impacts such as land-use change, timber harvesting, and corridor construction (highways, power line rights-of-way) are prohibited or limited by law. For research on landscapes and human effects under controlled conditions, groups of nearby experimental reserves are necessary.

Experimental Reserves

In the United States, there are large numbers of experimental reserves operated by a variety of Federal agencies, State governments, and private institutions. In general, these reserves constitute the experimental component of natural research laboratories, permitting both comparative research among different ecosystem types and different kinds of man-induced perturbations. The reserves exhibit a diverse array of independent, complementary, and overlapping responsibilities. Many of them compare functionally with reserves in the Soviet Union where manipulations are allowed (e.g., competition studies of V. P. Karpov carried out at the Central Forest State Reserve).

Currently, the many experimental reserves (Parsons 1975) under the jurisdiction of such agencies and private groups are being organized into a network of Experimental Ecological Reserves (The Institute of Ecology 1976). The key objectives of such a network are to:

(1) provide data on a number of ecological processes for a variety of ecosystem types ranging from self-regulated intact systems to those exhibiting the effects of various extreme disturbances,

(2) analyze the changes in ecosystem properties or process rates as the result of planned treatments,

(3) coalesce diffuse research activities and focus individual disciplinary efforts on integrated studies of complex ecological systems, and

(4) provide long-term data and insight on the effects of changing ambient environmental parameters on ecosystems and their constituents.

Sixty-seven research sites have been identified by The Institute of Ecology for inclusion into a national system of Experimental Ecological Reserves. These (1) represent the important ecological assemblages of the U.S., (2) provide accessibility and facilities for long-term research, and (3) protect land and waters for baseline monitoring, experimental controls and manipulative treatments. Point (3) relates directly to the recommendations of a U.S. panel (National Research Council 1976) on the Implementation of the Global Environmental Monitoring System (GEMS). They suggest "...the establishment of a global system of baseline and impact stations, with the former placed so as to represent the world's

major biome types, and with the latter paralleling the areas identified in the agriculture and land-use program [of GEMS]".

The inclusion of Experimental Ecological Reserves in the reserve cluster, as substitutes for or extensions of contiguous buffer areas, is critical to the attainment of the goals of a network of Biosphere Reserves as identified by the UNESCO Man and the Biosphere Program. The opportunity for manipulative, experimental research is their unique contribution to the reserve cluster, collectively representing and achieving the objectives of a Biosphere Reserve.

Intra-Reserve Comparability

A critical factor in the establishment of a reserve cluster relates to the extension of results between experimental and conservation reserves. A fundamental question is whether ecosystem responses following manipulations in nearby experimental reserves are indicative of such rates should they occur in conservation reserves. Optimally, experimental reserves should include tracts which represent regional variability and have many environmental features (e.g., elevation, bedrock types, vegetation) in common with the conservation reserve. Sometimes the conservation reserve can serve as a control for manipulations on nearby experimental tracts. If an experimental tract with the desired attributes is not available for inclusion, studies need to be conducted which can provide for the adjustment of process rates between reserve types. The work of Shanks and Olson (1961) stands as an example of this technique. Decomposition rates of fallen leaves were determined for an environmental gradient running from high elevations in the Great Smoky Mountain National Park to lower elevations at the Energy Research and Development Administration's (formerly Atomic Energy Commission) proposed Oak Ridge National Environmental Research Park. These data enable decomposition rates to be adjusted for elevation (moisture and temperature) within the Southern Appalachian region.

Studies from the full complement of reserves forming a gradient from pristine to heavily impacted can be organized to address another important question, "At what levels of disturbance do ecosystems begin to degrade or recover with unusual slowness?" Given enough variety of conditions in the cluster, the reserves can be aligned to represent ecosystems under a range of stresses. This re-emphasizes the need for variety in both natural and disturbed conditions when selecting reserves for inclusion in the cluster.

SOUTHERN APPALACHIAN MOUNTAIN REGION: EXAMPLE OF A RESERVE CLUSTER

The Great Smoky Mountain National Park, along the Tennessee-North Carolina border, and the nearby U.S. Forest Service Coweeta Hydrological Laboratory are the first cluster components to be officially designated as a Biosphere Reserve. Another nominated

experimental reserve in a neighboring geological province but in the same drainage basin is the proposed Oak Ridge National Environmental Research Park (NERP) of the Energy Research and Development Administration (fig. 2). The National Park represents the conservation

Figure 2. Example of a Biosphere Reserve Cluster from the Southern Appalachian region, southeastern United States. The major conservation reserve is the Great Smoky Mountain National Park. Partially surrounding it is a buffer zone (proposed). Nearby experimental reserves are the Coweeta Hydrological Laboratory and the proposed Oak Ridge National Environmental Research Park (NERP). Fringe areas include additional tracts which can augment studies carried out within the Biosphere Reserve Cluster.

"core area as defined by MAB (1974), and the Coweeta and Oak Ridge sites represent the separate but nearby experimental reserves. This reserve cluster is the example most familiar to us where a conservation area has been used in combination with nearby experimental tracts.

Work already completed within the cluster can serve as specific examples of the objectives of experimental reserves listed earlier.

(1) Provide data on a number of ecological processes for a variety of ecosystem types ranging from self-regulated intact systems to those exhibiting the effects of extreme disturbance.

The National Park Service encouraged experiments on the rate of litter decomposition and mineral cycling in the Great Smoky Mountain National Park for comparison with similar process rates at lower elevations at the proposed Oak Ridge Environmental Research Park (Shanks and Olson 1961, Witkamp and van der Drift 1961). Studies were also designed (e.g., Clebsch and Shanks 1962; Whittaker, Cohen, and Olson 1963; Sollins and Anderson 1971) so that both areas and other parts of the Eastern Deciduous Forest Biome would be represented by a coherent set of phytomass and production data. Rates of ecological processes have also been measured in the notorious Copperhill basin where ecosystem degradation by air pollution has proceeded to an extreme, illustrating one example of severe disturbance and also of some recovery by ecological succession (Witkamp, Frank, and Shoopman 1966).

(2) Analyze the attendant changes in ecosystem properties or process rates as the result of experimental landscape manipulations.

Treatments on several watersheds at the Coweeta Hydrological Laboratory have been assessed by their effect on components of the water budget and mineral cycling patterns (Johnson and Swank 1973). Some catchments have been converted to artificial communities. Results from tree plantations have illustrated changes on a landscape scale e.g., dense white pine (*Pinus strobus*) significantly reduced total water yield (Swank and Miner 1968).

Both Coweeta and Oak Ridge have additional sites which can be manipulated according to future research needs. Coweeta has limited areas committed for indefinite protection, but a large catchment is available for long-term control and comparison with manipulated catchments. The proposed Oak Ridge Environmental Research Park (Reichle 1975) has a number of unique natural areas under protection as well as potential catchments that can be manipulated and monitored.

(3) Coalesce diffuse research activities and focus individual disciplinary efforts on integrated studies of complex ecological systems.

Work completed during the International Biological Program addresses this objective. Hydrological and mineral budget studies at the Coweeta Hydrological Laboratory (conducted jointly by the U.S. Forest Service and the University of Georgia) were compared with those of the Walker Branch Watershed in the proposed Oak Ridge Environmental Research Park (Elwood and Henderson 1975). The latter watershed and nearby forests tagged with isotopes have been utilized for many multi-disciplinary ecosystem studies (Edwards and Sollins 1973; Goldstein and Harris 1973; Reichle, Goldstein, Van Hook, and Dodson 1973).

(4) Provide long-term data and insight on the effects of changing ambient environmental parameters on ecosystems and their constituents.

Collection of data useful for long-term assessments of environmental change requires stable ownership and land-use plans. Monitoring studies at the Coweeta Hydrological Laboratory have been uninterrupted since the mid-1930's. Watershed studies at Oak Ridge are more recent, but still span a period of over 10 years. In addition, a large number of permanent forest plots exist within and between experimental reserves which are re-measured at about 5-year intervals. Similar data have been utilized to project changes in the quality of the land cover over time (Johnson and Sharpe 1976) and to show the effect of air pollution on primary production (Whittaker, Bormann, Likens, and Siccama 1974). The current establishment of permanent plots in natural areas at Oak Ridge will provide the basis for determining additional changes in ecosystem parameters for the future. Finally, scientists have utilized both core areas (serving as controls) and experimental tracts to monitor trace environmental pollutants (e.g., Huckabee 1973).

COORDINATION AND INFORMATION SYSTEM REQUIREMENTS

"The ultimate objective of MAB Project 8 is to attain a coordinated network of biosphere reserves...linked by exchange of information...as part of the MAB Programme".[4] Of course, independent thought by creative individuals and groups is vital to enlarge our sources of hypotheses and organized information. It is equally important to ensure that such information is exchanged and utilized by the teams working at all levels of the Biosphere Reserve network.

Within a reserve cluster, methodology and schedules of measurement need to be worked out to enhance comparability, especially where conservation core areas are used as controls. At the national level, inter-agency cooperation is vital; and frequent bilateral or multilateral contact at the international level can lead to a truly global, well-integrated network of Biosphere Reserves. Thus, it is clear that frequent communication facilitated by a well-designed information system is an essential ingredient for success at all levels.

There are many advantages to having a well-designed information system that provides for the organization of data collected from the reserves, facilitates rapid exchange among scientific personnel working at Biosphere Reserves, and enables rapid updates in regional or global maps of pertinent variables. Several examples of such data base organization come from work completed during the International Biological Program (Reichle, O'Neill, and Olson 1973; Ulrich, Mayer, and Heller 1974).

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[4] di Castri, F. 1976. MAB circular letter 1/76. UNESCO, Paris

One rather simple need for assisting both the scientific and management applications of results from experimental reserves is a more orderly handling of spatial data. For communication purposes, we need maps of locations (e.g., latitude-longitude of research sites, monitoring transects, and boundaries of Biosphere Reserve zones which can be updated quickly. We believe computerized maps will help local groups and eventually help the whole global network to keep more currently informed than would otherwise be possible. For example, once tested locally, results for endangered species and habitat locations (Goff, Stephenson, and Lewis 1975) can readily be extended to large regions or continents (Schreiber et al. 1974) or to a global geodetic framework. Figure 3 shows altitude as well as latitude and longitude for the Appalachian Mountain area, including the Great Smoky Mountain National Park and the proposed Oak Ridge Environmental Research Park. Figure 4 shows primary productivity at the national level derived from statistical relationships between climate and production (Sharpe 1975). Figures 3 and 4 were drawn by computer from data stored by geodetic coordinates.

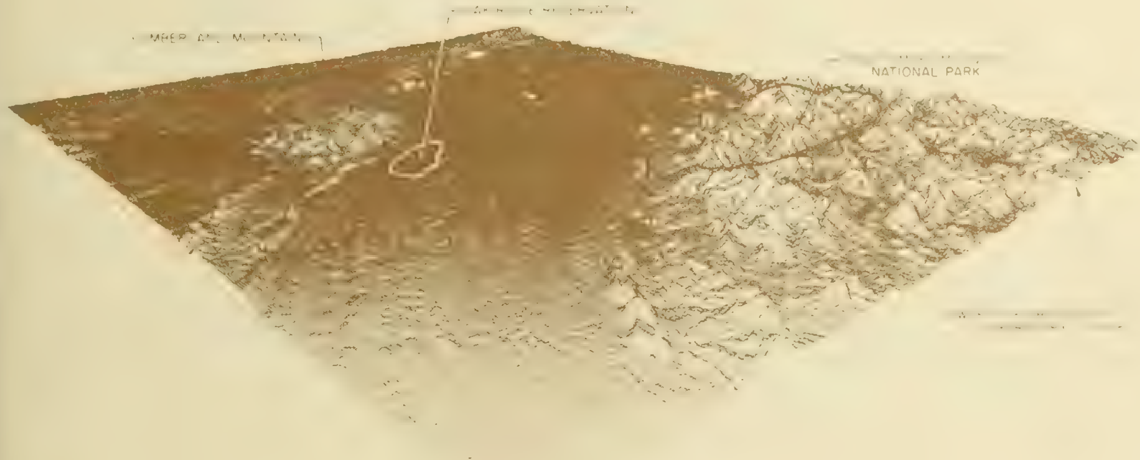

Figure 3. Computer-drawn map (Durfee 1974) of eastern Tennessee utilizing latitude-longitude and elevation data. To the right are the Southern Appalachian Mountains (Great Smoky Mountain National Park and the Coweeta Hydrological Laboratory), in the middle the Ridge and Valley Physiographic Province (proposed Oak Ridge National Environmental Research Park), and to the left the Cumberland Plateau and Mountains.

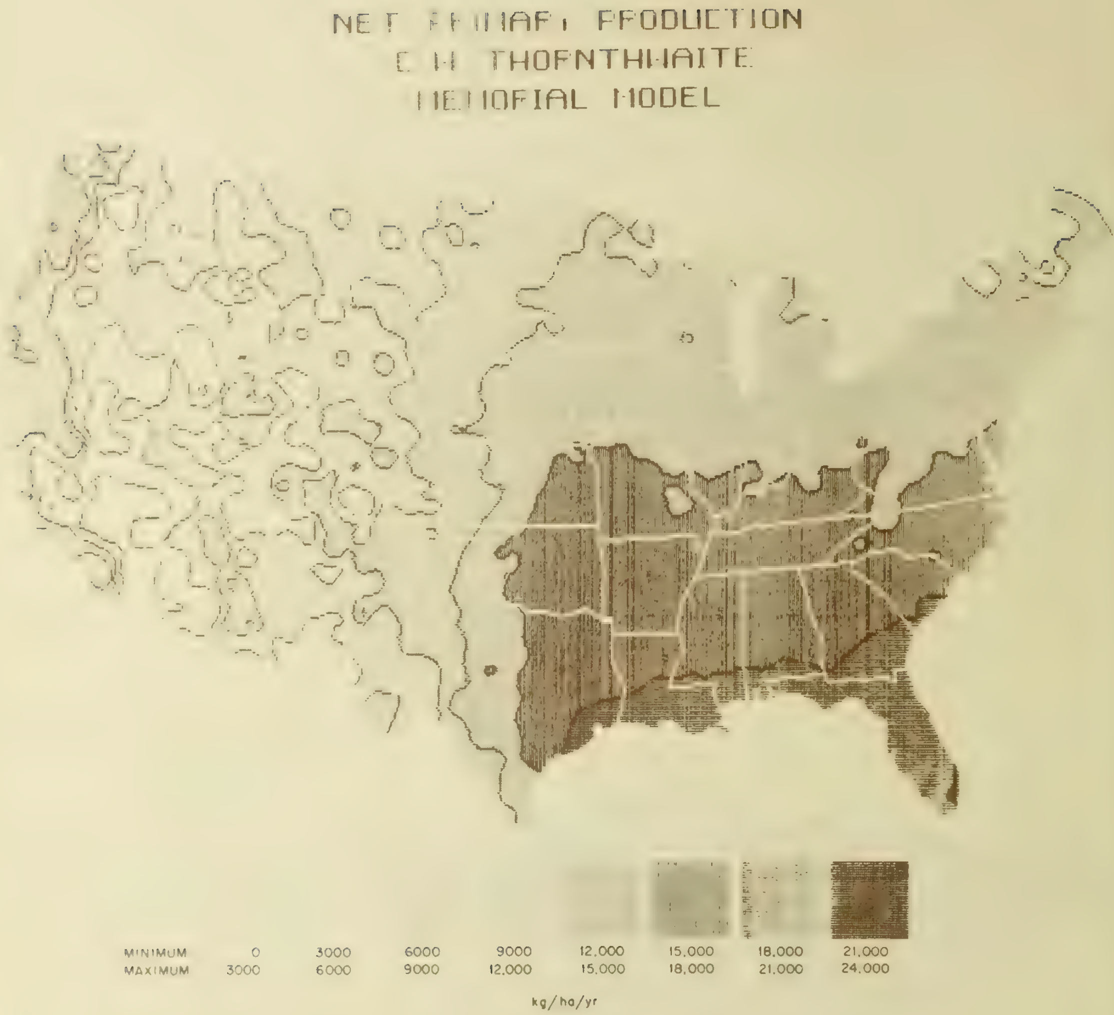

Figure 4. Computer-drawn map of net primary production within the conterminous United States (Sharpe 1975). Values are kg/ha per year, and were derived from a regression of net primary production and average annual water balances.

SUMMARY AND CONCLUSIONS

The organization of the Biosphere Reserve network proposed for U.S.-U.S.S.R cooperation and for broader coordination with UNESCO/MAB illustrates problems which each nation must face in combining conservation with research. The cluster of reserves is proposed as one means to address the diverse goals of the Biosphere Reserve network. The linkage of experimental and conservation reserves will provide information on ecological processes under anthropogenic and natural control. The natural areas under protection with experimental areas

promise to provide better representation of regional variability. Success of the program depends heavily on the active exchange of ideas and information at all levels of the reserve network.

Many of the urgent environmental problems to be solved by experiments and other research are often in locations which are not permanent enough to assure the continuity of records necessary for monitoring the continual changes in the biosphere. The Experimental Ecological Reserve Network will add continuity by providing a coherent set of areas for active research, bringing together the areas, interests, and expertise represented by diverse institutional staffs.

For the synthesis of results, both frequent communication among participants and a well-designed information system are vital. Such an information system should include spatially defined data which will facilitate the use of computers to update maps and other graphic representations of information collected at Biosphere Reserves.

Considerable momemtum is forming in the United States regarding the implementation of a Biosphere Reserve network; however, we need to take fuller advantage of the ideas and information from different groups which will lead to a better understanding of the larger regions represented by the whole set of reserves.

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GLOSSARY

BIOSPHERE RESERVE - Representative landscape unit reserved through the UNESCO- Man and the Biosphere Program for purposes of conservation, monitoring, and/or research. May include completely natur as well as semi-natural ecosystems.

BIOSPHERE RESERVE CLUSTER - A group of adjacent, but usually geograph ically separate biosphere reserves of both experimental and conser vation types organized to address the complex objectives of the biosphere reserve network. Proposed by the United States to satis UNESCO-MAB objectives calling for the study of both natural and ma disturbed landscapes.

BIOSPHERE RESERVE FRINGE - Area beyond peripheral buffer zone which connects and/or surrounds a biosphere reserve cluster, but normall including more diverse land uses and ecosystem complexes than the reserves. Made available for studies of ecosystem disturbance and recovery, and of social impact and interactions with biota.

BIOSPHERE RESERVE NETWORK - The global set of biosphere reserves or reserve clusters linked by international understanding of purposes standards, and exchange of information and personnel.

CONSERVATION RESERVE - Landscape unit established to conserve the diversity and integrity of biotic communities of plants and animal within natural ecosystems, and to safeguard the genetic diversity of species.

Background monitoring and research on the effects of recreational use are frequently conducted in such reserves. Landscape manipulations are usually restricted or prohibited. Examples include National Parks, Wilderness Areas, and conservation-type Biosphere Reserves.

CODE AREA - Geographical subdivision of a biosphere reserve devoted almost wholly to conservation.

EXPERIMENTAL RESERVE - Landscape unit established to evaluate major anthropogenic effects (pollution, harvesting, land-use change) on local and regional ecosystem structure and function. Monitoring of ambient conditions is frequently carried out as well.

EXPERIMENTAL ECOSYSTEM RESERVE NETWORK - Set of experimental reserve in different biogeographic provinces of the United States which offer the opportunity for experimental, manipulative research to evaluate the impacts of current, planned, and as yet unforeseen activities of man.

PERIPHERAL BUFFER ZONE - Geographical subdivision of a biosphere reserve which surrounds and hence protects a core area, and where the effects of landscape manipulations on ecosystem structure and function can be assessed.

Research, Monitoring, Inventory, and Education at Great Smoky Mountains National Park

by

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GENERAL DESCRIPTION, PURPOSE AND USES OF THE PARK

Great Smoky Mountains National Park is a 208 370 hectare natural area whose resources the Federal Government set aside, in 1934, to be preserved for the benefit and enjoyment of this and future generations. In 1975 alone, the Park experienced eight and one-half million visits by individuals who came to enjoy viewing its massive, rugged mountains, the lush abundance and diversity of its plant life, and the varied animal life that thrives in its unspoiled wildlands. In several historic zones within the Park visitors may see and learn something about the homes, barns, mills, and churches which are preserved as reminders of the distinctive pioneer culture that once characterized the southern Appalachians.

The Park is within 2 days' easy driving distance of nearly two-thirds of the population of the United States. Most visitors come from the nearer Midwestern and Southern States, but it is also a focal point of national and international interest.

SPECIAL QUALITIES OF THE PARK

Although the Smokies rise more than a mile above the adjacent lowlands (Park elevations range from 240 to 2 040 meters), and its slopes are extremely steep, the visual impression given is of worn, massive ridges fading into blue distances. Lacking the jagged spectacle of the Rocky Mountain and Sierra Parks, the gentle beauty of the Park is augmented by its appeal as the largest terrestrial sanctuary in the Eastern United States — and by the extraordinary quality of its ecosystems. For most who come to the Park, the experience enjoyed centers on touring parts of the more than 300 kilometers of primary roads. Studies, however, indicate that a major aspect of the pleasure they derive from the Park comes from knowing that most of it is wilderness, unspoiled by roads, buildings, other developments, or the activities of mechanized equipment. In addition, more than 120,000 visitor nights of backcountry camping and at least 800,000 instances of day-hiking, annually, provide visitors with experiences not duplicable elsewhere — experiences the quality of which engenders, among many, an intense feeling of loyalty to the principles of wilderness preservation.

The specific natural qualities that make the Smokies especially valuable to those who perceive them — whether casual visitor, hiker, or scientist—include:

- Very high diversity of temperate flora (about 1,400 species of flowering herbaceous plants, 2,200 other plant species), with large numbers of species occurring in the same stands. One of its major forest types, the Cove Forest, has 25 to 30 tree species, with 6 to 12 dominant on any one site. A one-tenth hectare plot may support 40 to 50 species of herbs.

- Flora highly representative of the Eastern Forest Biotic Province over continuous gradients in both disturbed and undisturbed ecosystems, and over a wide range of elevations and exposures. Those areas previously cut over have been recovering for varied periods of time, thus representing diverse successional stages.

- Ecosystems stability, as a result of protection from excessive human impacts and of the diversity of life forms composing the Park's ecosystems.

- Associated with such diversity of flora and site conditions, a highly diverse array of animal species, some of them spectacular and appealing to the public (e.g., black bear, white-tailed deer, wild turkey, and the rare mountain lion), and others of special scientific interest.

- Numerous watersheds in which thousands of hectares of roadless terrain feed streams whose purity is unexcelled by streams of comparable flow and accessibility anywhere in the United States. Some of these watersheds are unaffected even by trails. Approximately 500 billion gallons of surface water flow from the Park each year. (Annual rainfall in the Park ranges from 1 200 to 2 500 millimeters)

- Large expanses of virgin forest, totaling about 70,000 hectares (an imprecise figure, as some areas were logged so selectively—and long enough ago—that it is difficult to be sure how much was never logged). Dominant tree species include *Abies fraseri* (Fras[er] fir), *Acer rubrum* (red maple), *Acer saccharum* (sugar maple), *Aesculus octandra* (yellow buckeye), *Betula alleghaniensis* (*B. lut*[*ea*]; yellow birch), *Carya* species (hickories), *Fagus grandifolia* (beec[h]), *Picea rubens* (red spruce), *Halesia carolina* var. *monticola* (silve[r]-bell), *Liriodendron tulipifera* (tulip poplar), *Pinus* species (pines), *Quercus* species (oaks), *Tilia heterophylla* (basswood), *Tsuga canadensis* (hemlock).

- The largest block of virgin red spruce forest remaining on earth, and North America's southernmost limit of the range of that and many other northern species.

- Extensive areas sheltered from the effects of many of the air pollutants that affect most of the Eastern United States. (Sulphates and nitrates are coming in, however).

- Preservation in perpetuity (thus giving long-term research opportunities not assured elsewhere) of many plant and animal species which are uncommon, endemic, or exist outside of the Park only as fragmented populations. These are essentially free from major human interference, interruption by roads, and impairment by such things as housing areas or industrial developments. The value of the gene pools thus protected is beyond estimation.

- Ease of access, because of its proximity to major population centers—and, internally, by virtue of its extensive trail system (more than 1 200 kilometers maintained).

- A large accumulation of data, as a result of the unusual amount of scientific interest that has centered on the Smokies over the years.

FACTORS INFLUENCING ECOSYSTEMS INTEGRITY

Human enjoyment is a basic reason for the establishment of Great Smoky Mountains National Park; and the ways in which people enjoy the Park affect, to various degrees, the integrity of its resources. Accepted uses include touring Park roads by motor vehicles; camping in the 1,100 individual sites provided in the nine campgrounds accessible by automobile; day-hiking; backpacking for stays of 1 or more nights in the backcountry campsites (118 of them, of which 20 have a lean-to shelter); trout fishing, wading, swimming, and floating (mostly on inner tubes) in or on the creeks and rivers; horseback trips, by the hour or for as much as several days and nights in the roadless areas; participating in various interpretive activities (self-guiding or with the guidance of staff interpreters); and such associated pastimes as photography, meditation, wildlife observation, and other forms of informal nature study.

Most of these uses bring direct physical impact on resources—as do most research activities in the Park. I believe we must ultimately face the fact that impairment of pure natural conditions begins with the first footstep by a person wearing modern footgear, or incursion by an exotic species, and ranges to the total obliteration of areas by paving. Where we draw the line depends, finally, on subjective judgment. In making decisions that may have significant ecological, social, or economic impacts, we are required by law to make public our analysis of such impacts, and to take into account the views of all interested parties, governmental and private. as expressed through written comments, public hearings, or both. No decision is likely to satisfy everyone; and in any case, the Park is not, and cannot be totally free of the influences of modern technological humankind. The extreme ruggedness of its terrain and density of its vegetation, though, are such that most visitor use is concentrated along its roads and maintained trails—leaving virtually intact a large number of areas within the Park, each of which is larger than many entire Reserves.

The Park is surrounded by a population that includes many whose forbearers harvested the plant, animal, and mineral wealth of the

area with little or no outside control. Some of these (and other) people continue such activities, illegally, in the Park. Bear, deer, grouse, and other animals are killed; and various plants are removed (most notably, ginseng and ramps). Some thoughtless or uninformed visitors collect flowers and shrubs, carry away attractive rocks, or kill animals which they consider undesirable (e.g., poisonous snakes). A protection staff varying, seasonally, from 35 to 55, carries the primary responsibility for controlling such activities.

Its value as a place for non-disruptive scientific research is high among the reasons for Great Smoky Mountains National Park's existence as a Park. Substantial effort is now being made to facilitate such research whether aimed at the solution of immediate management problems or simply the increase of human knowledge of the environment and its components.

RELATIONSHIPS BETWEEN MANAGEMENT AND RESEARCH

Much of the management effort in the Great Smokies is now directed at keeping human impacts at as low a level as is possible, given the kinds and amounts of uses that are expected and accepted. For that reason, research efforts funded by the National Park Service are directed primarily at monitoring such impacts, and at developing methods for reducing, eliminating, or compensating for them. Such research is done by National Park Service employees, or under contracts with universities or private firms.

A great deal of other research is done in the Park, though, by scientists whose interests don't relate so clearly to our management concerns, but who are supported by funds from other sources. Such sources include other Federal agencies (National Science Foundation, RAND, ERDA, EPA), private foundations, privately endowed conservation organizations, and even interested individuals financing their own research or that of others. Much of the information gathered in such projects eventually will become very valuable to management of the Park's resources—or is immediately valuable in making management decisions affecting other aspects of the human environment.

The Park has already attracted much scientific interest (at least 1,000 scientific papers have been published, relating to the Park), but the role of Service personnel in conducting or supporting research has varied from time to time. At Great Smokies, as throughout the National Park System, awareness of research values and needs is at a new high, and is apparently ascending.

We are now making concerted efforts to conduct and coordinate research under the guidance of highly qualified professional scientists. The work is being conducted with the newly established Uplands Field Research Laboratory in the Park as its base. Emphasis is on the solution of obvious management problems. Included among these are such things as work on the dynamics of the Park's population of exotic wild boar (which arrived, uninvited, more than 30

years ago), and the means of bringing it under control; the influence of certain exotic plants; the influence of the balsam woolly aphid; the impacts of hiking, horseback riding, and camping on Park ecosystems; methods by which certain communities (grassy balds) may be held at a seral stage deemed desirable because of their unique qualities; and the dynamics of the Park's native brook trout population as it relates to human activities; and the effects of two exotic species of trout.

But we have a long way to go. Unfortunately, we are faced with the necessity of answering these management problems without benefit of an adequate systematized base of inventory work. Inventorying must therefore be accomplished while we are coping with the management problems. Such inventorying includes work as basic as the development of a reasonably detailed vegetation map of the Park; stream classification; rare and endangered species survey; soils mapping; and fuel-loading mapping. With assistance from other agencies (for example, ERDA, the Weather Service), we must monitor as thoroughly as possible the full spectrum of factors influencing the environment, including weather, air and water pollution, and animal population trends. By such means, it should be possible for us to recognize problems before they become serious, or preferably to foresee them in time to take the steps necessary for avoiding them.

Dr. Stanley Cain, whose ecological studies are among the most significant done in the Park, developed information from which the following elements—representing probably the minimum considerations that should be included in the Park's ecological research programs—were derived:

1. Continuing program of floristics and faunistics, with suitable museum and herbarium vouchers for species present in the Park.

2. Basic description of the composition and structure of the Park's vegetation and associated animal life—(a) existing communities (major cover types and special habitats); (b) how component species are organized; (c) indicator species for given community or ecologic situations; (d) successional patterns in various communities.

3. Biogeographic features—endemics, range extremes.

4. Rare and endangered species.

5. Predator-prey relationships, food chains.

6. The nature of territories, ranges, carrying capacities, population cycles.

7. Phenological data.

8. Quantitative study of the trophic levels of biotic communities, including periodic censuses of the dominant vertebrates and invertebrates and estimates of the biomasses, fecundity and rate of turnover of the most important populations.

9. Analysis of climatic trends.

10. Detailed soil survey.

11. Conditions in undisturbed environment as it may have existed before the arrival of European man—(a) variations of current ecological conditions from the original; (b) factors that caused these deviations; (c) the practicability of recreating original ecological conditions where impairment has occurred.

12. The direct effects of visitors on important natural features.

Research projects may be funded by the National Park Service, other Federal agencies, State agencies, universities, or private sources. Any one of them may involve personnel and funds from more than one of those sources.

Since the Park's establishment, hundreds of scientists have undertaken a broad range of research projects. The greatest emphasis has been on vegetational research, but many of the animal groups, particularly salamanders, have also been investigated and there have been a number of geological studies.

More than 80 separate projects were in progress from 1972 through 1975, and during that time approximately 20 were completed. Most of the research is the work of university faculty and students, but in some cases projects are undertaken by National Park Service employees.

Past studies include significant vegetational research by Cain (1930a, 1930b, 1931, 1935, 1936, 1943, 1945), Shanks (1954a, 1954b, 1956) and Whittaker (1956, 1961, 1962, 1963, 1966); the early vegetational mapping that was done by Miller (1941); studies of grassy bald succession by Gersmehl (1970), Lindsay (1976), Mark (1958, 1959) and Wells (1936a, 1936b, 1938); a plant reference list compiled by Hoffman (1964, 1966), and the investigations of fungi by Hesler (1960, 1976) and bryophytes by Sharp (1936, 1939; Cain and Sharp, 1938).

As for important studies related to the Park's fauna, Barr (1962, 1969a, 1969b) has worked on the carabid beetle fauna; Whittaker (1952) studied the summer foliage insect communities; and King (1937, 1939a, 1939b, 1942, 1944) reported on trout management studies, and surveyed the herpetology of the Park. Hairston (1949, 1950, 1951), Highton (1962, 1971; Highton and Henry, 1972), Huheey (1959, 1960, 1961, 1966a, 1966b; Huheey and Brandon, 1973), Tilley (1968, 1973, 1974) have done a considerable amount of research on the ecology, geographic variation, and distribution of plethodontid salamanders. Bird life has been investigated by Ganier (1926, 1931, 1962; Ganier and Clebsch, 1938), Stupka (1963) and Tanner (1952, 1955, 1957); the ecology of the European wild boar has been investigated by Bratton (1974, 1975a, 1975b) and considerable information on the ecology of the black bear in the Park has been contributed by Pelton and his students (Pelton 1970, 1974, 1976; Pelton and Burghardt, 1976; Beeman 1971, 1975; Eubanks, 1976; LaFollette, 1974; Marcum, 1974).

Much of what is known about the Park's geology is summarized by King, Neuman and Hadley (1968).

Proper management of the Great Smoky Mountains National Park—management to assure continued enjoyment of its distinctive qualities, and the full measure of knowledge that may be derived from study of its undisturbed natural resources—is dependent on effective research, monitoring, and inventory. This work can be done with maximum efficiency only if done with full knowledge of work being done in similar or related areas around the world. The MAB program offers our greatest hope for sharing with you and other nations the benefits of all such work.

EDUCATION IN THE PARK

A major aspect of Park operations is its interpretive program, through which public perception, understanding, and appreciation of its features and values is developed. This program, conducted by a staff ranging in number, seasonally, from 8 to 72, includes the preparation and presentation of publications, exhibits, slides, films, audio devices, guided walks, auto caravans, and hikes, and talks. The planning and production of many of our interpretive devices is done with the assistance of the National Park Service's Harpers Ferry (West Virginia) Center, by use of the Center's specialized personnel or by contracting with private firms. The Park is thus a part of a national network of educational resources focusing on outstanding natural and cultural values.

Several thousand students from elementary and secondary schools throughout the Southeastern States are given week-long training sessions based on the Park's natural environment, at the Tremont Environmental Education Center. This facility, built by the U.S. Government, is managed under a contract with Maryville College. It operates at capacity throughout the school year. In addition to its programs for young students, it provides training for teachers and prospective teachers in the concepts and techniques of environmental education—thus encouraging both improved effectiveness in student use of the Center, and continuing influence beyond the immediate experience at the Center.

College students are deeply involved in research in the Park. Interns at the undergraduate level assist in the subprofessional aspects of research work, thus preparing themselves for work at the professional level. Much of the research itself is done by graduate students, guided by qualified academicians and with broad coordinative direction from the Service's professional personnel. Our knowledge of Park resources is thus increased by a process that is integral to the development of scientists competent at the highest professional level. College students also receive instruction from Park personnel during group field trip visits.

The exceptional diversity of the Park's life forms and terrain, the extent of its ecological integrity, and the presence of highly qualified personnel, make it particularly valuable as a place for the training of National Park Service (and other government) personnel. Although such training has been largely on a one-by-one basis (special assignments, temporary details), plans are now being considered for

the use of the Park in the training of groups of personnel engaged in 1- or 2-week sessions dealing with resource management and other aspects of natural area operations.

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Monitoring on Biosphere Reserves for Regional Background Levels of Pollutants

by

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INTRODUCTION

Man's impact on the environment has had a far-reaching and at times a catastrophic effect. Long gone are the days when the pollution emitted by man impacted only his immediate surroundings. Today, pollution problems are truly global in nature and transcend any or all national or political boundaries. This problem is becoming even more critical now that much of the world is facing an energy shortage. Many nations are being forced to turn from oil to potentially more environmentally harmful fuels such as coal. In addition, even supposedly "clean" alternate energy such as geothermal resources have the potential for environmental contamination from a number of trace elements and gases. The Study of Critical Environmental Problems Report (Massachusetts Institute of Technology 1970) stated: "Over the past few years, the concept of the earth as a 'spaceship' has provided many people with an awareness of the finite resources and the complex natural relationships on which man depends for his survival. These realizations have been accompanied by concerns about the impacts that man's activities are having on the global environment. Some concerned individuals, including well-known scientists, have warned of both imminent and potential global environmental catastrophes."

The task of estimating the extent and the magnitude of man's impact on the global environment is challenging. Morgan et al. (1975) said, "Man's technological advances and increasing population have caused a significant impact on our environment. We are now faced with the

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arduous task of describing on a global basis those factors that impinge on environmental quality. This information is needed by both the researcher and the official who must not only assess environmental quality, but also control emissions into all aspects of the environment."

There has been a tremendous amount of discussion, meeting, and thought given to a Global Environmental Monitoring System (GEMS). A variety of organizations and committees, including but not limited to the U.S. International Task Force of the Global Network for Environmental Monitoring, the Global Monitoring Task Force of SCOPE, the Man and Biosphere Expert Panel on Pollution, the SCEP, Task Force II--Committee on International Environmental Affairs, and the SCOPE Commission on Environmental Monitoring and Assessment have called for the formation of such a global monitoring network.

The United Nations' Conference on Human Environment (Man and Biosphere 1974) held in Stockholm in June 1972, recommended the establishment of EARTHWATCH, which has a four-pronged program including monitoring, research, evaluation, and information exchange. The ultimate objective was the establishment of GEMS. The seven program objectives of GEMS are:

1. *An Expanded Human Health Warning System*

   Selected health effect indicators and associated environmental parameters will be monitored so as to provide for early detection of potentially harmful conditions. The disease statistics now compiled on a global scale from ongoing national and international health activities would be augmented to provide for improved warnings.

2. *An Assessment of Global Atmospheric Pollution and Its Impact on Climate*

   The network of atmospheric baseline monitoring stations now being developed would be expanded to provide for a more comprehensive assessment of pollutant and climate trends. Measurement of additional critical pollutants would be made as part of a global monitoring network.

3. *An Assessment of the Extent and Distribution of Contaminants in Biological Systems, Particularly Food Chains*

   Potentially harmful contaminants in food would be monitored to provide early warnings for protecting human health. Existing national and international programs for monitoring harmful pollutants in fish and other food prominent in international trade provide a base for implementation.

4. *An Improved International Disaster Warning System*

   Countries in regions of high natural disaster potential will be assisted by teams of technical specialists to establish plans for regional monitoring systems and centers, as well as predisaster preparedness. Atmospheric, oceanic, volcanic, and earthquake hazard warnings will be addressed.

5. *An Assessment of the State of Ocean Pollution and Its Impact on Marine Ecosystems*

Selected pollutants will be monitored at a small number of remote locations in the world's oceans on a continuing basis to assess long-term trends. Major sources of ocean pollution which contribute to regional contamination, such as river outflows, will be monitored to complement baseline observations and permit assessment of impacts on regionally important ecosystems. The interaction of the ocean, land, and atmosphere in pollutant transport will be assessed.

6. *An Assessment of the Response of Terrestrial Ecosystems to Environmental Pressures*

The direct and indirect impact of environmental pressures, anthropogenic and natural, on terrestrial ecosystems will be monitored. Ecosystem monitoring programs presently underway will be expanded to focus on ecological areas presently not receiving adequate attention.

7. *An Assessment of Critical Problems Arising from Agricultural and Land-Use Practices*

Certain aspects of agricultural and land-use practices will be monitored for their environmental effects on natural systems.

As part of this global and environmental monitoring system, it has been recommended that Biosphere Reserves be established. For example, the U.N. Conference on the Environment (1972) recommended that biological reserves be established within the framework of the report "Man's Impact on the Global Environment" (Massachusetts Institute of Technology 1970) which recommended similar type entities calling them ecological baseline stations in remote areas on Biosphere Reserves.

Biosphere Reserves may be defined as undisturbed and protected natural background areas of the earth where life naturally occurs and interaction takes place among the living organisms and with the non-living environment.

The needs for these Biosphere Reserves are obvious.

1. They provide a permanent record of the "natural" state of the environment.

2. They would ensure undisturbed areas from which background data on pollutant levels could be obtained.

3. They can potentially serve as early warning sites for more dangerous buildups in higher impact areas.

4. They serve as repositories for natural sources of genetic pools of animal and plant species.

ENVIRONMENTAL MONITORING

Environmental monitoring is defined as the systematic collection of physical, chemical, biological, and related data pertaining to environmental quality, pollution sources, and other factors that influence or are influenced by environmental quality. Environmental quality data are vital in determining the exposure of critical populations at risk and include measurement of pollutant concentrations in air, water, soil, and food at locations where exposure may occur. The complexity of environmental or exposure monitoring can be appreciated if one considers that acute or chronic effects may result from either a single short-term peak exposure, repeated short-term high-level exposures, or a low-level long-term exposure. Further, one must consider the possibility that a single pollutant may cause or contribute to the aggravation of several different environmental effects. Frequently, the environmental contribution in such cases can only be recognized because of an increasing level of adverse effects, such as elevated rates of cancer in relatively isolated areas. In many instances, measurements of pollutant levels in areas designated as clean, i.e., Biosphere Reserves, can give man a clue or a warning of potential environmental danger, particularly from adverse synergistic effects that may be masked in areas of high impact. Thus, there is a requirement for a better quantitative measurement of exposure of Biosphere Reserves to the adverse effects of background levels of biological, chemical, and physical agents.

The relationship between elevated short-term exposures or acute exposures and adverse environmental effects is more easily recognized than is the case for long-term low-level exposures. In order to support research on long-term environmental changes in Biosphere Reserves, an integrated monitoring system is necessary to furnish an accurate estimate of exposure. While measuring the exposure of a receptor to chemical or physical agents, data from the integrated monitoring system would be used to quantitate the contribution of each pathway and the chemical or physical forms of the pollutants present. Exposure assessment must also consider such variables as frequency, duration, and intensity of exposure and necessary supporting data such as temperature, humidity, etc.

The monitoring of air, water, and soil, along with tissues and biological fluids collected from plants, wildlife, and domestic animals, can indicate levels, patterns, and trends of environmental pollutants or their metabolites. The health, growth, and number of plants or their accumulation of pollutants may be a useful indicator or early warning of environmental contamination that may adversely affect human health. For example, some lichens are extremely sensitive to sulfur dioxide. In addition, incidences of pollution may be detected by unusual changes or mortality in animal populations in Biosphere Reserves; for example, those documented following exposure to DDT, mercury, lead, fluorides, and aflatoxins. Exposure or receptor monitoring is also required for developing and verifying predictive models linking source emissions to ambient levels.

Exposure monitoring may be done at fixed or movable ground stations or from aircraft. The sensors used may be for contact sensing point measurements or for remote sensing long-path measurements.

All monitoring systems must consider the following aspects in the design stage:

1. Station siting.
2. Sampling.
3. Sample handling.
4. Sample analysis.
5. Data storage and retrieval.
6. Representativeness of data and reporting format.

In addition, the frequency of sampling and the sampling time are important variables to consider as they relate to the monitoring objectives.

CRITERIA FOR ESTABLISHING SAMPLING SITES IN BIOSPHERE RESERVES

The criteria for sampling sites in Biosphere Reserves have been established, to a large extent, by existing programs. Criteria for establishing Biosphere Reserves sites have been proposed in a variety of reports. These include Morgan et al. (1975), the Report of the Ad Hoc Task Force on GNEM (1970), the SCOPE Report 3 (Munn 1973), and MAB Report 22 (Man and Biosphere 1974). From these reports one can readily draw a list of criteria as follows:

1. The stations should be located in an area where no significant changes and use practices are anticipated for at least 50 years within 100 kilometers in all directions from the stations.

2. They should not be downwind or downstream from major sources of pollutants and should be located away from major highways and air routes.

3. The sites should be at least 100 kilometers from urban centers over land and at least 150 kilometers away from urban centers if maintained along major rivers. The site should experience only infrequent effects from local natural phenomena such as volcanic activity, forest fires, and dust or sand storms.

4. The observing staff should be small in order to minimize the contamination of local environment by their presence in their living quarters.

5. All requirements for eating and cooking, etc., should be met by electrical power generators away from the site.

6. Access to the station is limited to those necessary to the operation of the station.

7. The reserved land areas should be protected from nonessential people and vehicles, but should not be fenced to the extent that natural movement of animals is significantly curtailed.

The question now becomes the number and precise location of the sites. An actual location within a biome will probably be determined by the criteria for establishing it. The number of locations which will meet the rigorous requirements for siting is probably limited In addition, resources to fund and study the sites are also limited. Hence, the selection criteria exert a self-limiting influence on the problem. Here we must pause and confine this discussion to terrestrial sites to obtain some perspective of operational fund requirements. Morgan et al. (1975) estimate that the cost of operating an on-site continuous monitoring station could range between $100,000 to $375,000 a year in U.S. dollars. Obviously, cost is a major consideration in establishing such a monitoring effort.

A list of pollutants is given in MAB Report 20 (Man and Biosphere 1974b). Also, pollutants are listed in the GNEM Report (Ad Hoc Task Force on GNEM 1970) and the SCOPE Report (Munn 1973). From these, we can draw a tentative list for monitoring the Biosphere Reserve (table 1).

Table 1--Suggested list of pollutants considered to be monitored at Biosphere Reserve sites[1/]

Pollutant	Environmental component				
	Air	Surface water	Ground water	Soil	Biota
Sulfur dioxide	X	--	--	--	--
Suspended particulates	X	--	--	--	--
Turbidity	X	X	--	--	--
Chlorides	--	X	X	X	--
Biochemical oxygen demand	--	X	--	--	--
Dissolved oxygen	--	X	--	--	--
Coliform bacteria	--	X	X	--	--
Phosphorus (PO_4)	--	X	X	X	--
Organic nitrogen	--	X	X	X	--
Ozone	X	--	--	--	--
DDT and other	X	X	X	X	X
Chlorinated hydrocarbons	--	--	--	--	--
Cadmium	X	X	X	X	X
Mercury	X	X	X	X	X
Lead	X	X	X	X	X
Arsenic	X	X	X	X	X
Nitrogen dioxide	X	--	--	--	--
Carbon monoxide	X	--	--	--	--
Fluorocarbons	X	--	--	--	--
Reactive hydrocarbons	X	--	--	--	--

[1/] Other items for measurement, although not necessarily pollutants, are solar radiation, meteorology conditions, rainfall, soil characteristics, hydrology, and biological characteristics.

For the most part, adequate baseline data can be obtained for approximately $100,000 per station per year. For any monitoring station a subset of pollutants should be selected from table 1 to meet the objectives of the monitoring program. Also, continuous monitoring is not required for all pollutants. Statistically valid data may be obtained by selecting an appropriate intermittent sampling scheme and by the use of composite samples when possible.

The priority for pollutants at a given Biosphere Reserve should be selected based on an agreed set of criteria. All of the criteria noted below should be taken into consideration when establishing priorities:

1. Severity of suspected or known adverse effects on the biological populations of the Biosphere Reserve.

2. Persistence of the pollutant in the environment, resistance to environmental degradation, and accumulation in man or the food chain.

3. Conversion to more toxic substances.

4. Ubiquity and abundance in the environment.

5. Size and type of population exposed, frequency and magnitude of exposure.

6. Physical effects on the Biosphere Reserves such as soil permeability, etc.

7. Availability of adequate methodology for sampling and analysis.

QUALITY ASSURANCE COMPARABILITY OF MEASUREMENTS AND DATA QUALITY CONTROL

A basic requirement of any national or international monitoring program is that the data generated by one program or monitoring system be fully comparable to similar data produced elsewhere or at another time. In other words, the degree of accuracy and precision of all data must be known. This necessitates an active quality assurance program. Quality assurance can be defined as maintaining a certain prescribed standard of performance or output throughout the monitoring operations from beginning to end.

Various laboratories employ different methods for analyzing environmental samples. The analytical techniques, instrumentation, calibration procedures, analytical technicians, and chemical reagents used, usually differ both from laboratory to laboratory and over a period of time for a given laboratory. These interlaboratory and intralaboratory differences often lead to important systematic discrepancies between measurements of pollutant concentrations in the same matrix material. An effort should be made to overcome these difficulties by the use of reference methods. Some national and international groups have already selected such methods for several environmental agents and agreed upon approaches for the evaluation of equivalency.

As related to the monitoring of Biosphere Reserves, quality assurance applies to many areas such as personnel, equipment, data, and procedures. It applies not only to the component aspects of a monitoring system but also to their interrelationships and functions as a whole system. Therefore, quality assurance must be considered in the design, implementation of, and assurance of adherence to guidelines in the following areas:

1. Site selection.
2. Site verification.
3. Type and number of stations.
4. Selection of instruments and methods.
5. Sampling procedures.
6. Sampling frequency.
7. Instrument maintenance and calibration.
8. Historical operational records.

Other related areas which must also be considered with the above list are training and evaluation programs, calibration standards and their proper use, data handling, verification, storage, and coordination, and communications.

A total quality assurance program which implements the above principles would consist of four major elements.

1. Development and issuance of procedures.
2. Intralaboratory quality control program.
3. Interlaboratory quality control program.
4. Monitoring program evaluation.

All of these elements are equally essential and must be developed and carried out simultaneously.

THE MONITORING NETWORK SYSTEMS

Integrated monitoring systems should be established in a variety of Biosphere Reserves representing the critical natural biomes. The main elements for such systems are:

1. Design of suitable monitoring systems.

2. Instrumentation and methodology standardization and quality control.

3. Field sampling and measurements of environmental quality, emissions, and effluents.

4. Laboratory analysis and evaluation of field samples.

5. Information synthesis including operation of technical information systems, data analysis, and preparation of reports.

As part of the integrated monitoring approach to the Biosphere Reserves, it is proposed that the source-to-receptor concept be employed at each site. In this particular case, the immediate source is going to be general environmental transport. In a remote site, it is difficult to envision any other source for pollutants unless the site is downwind or downstream from a nearby major pollutant source. This very fact, however, may preclude the selection of that location as a Biosphere Reserve site.

For the purpose of the following scenario, the integrated design will be approached with the idea that the primary source of the pollutant is general global atmospheric fallout. The critical receptor for the pollutants is the Biosphere Reserve site itself. As the knowledge of that site increases, one's ability to conduct biological monitoring surveys increases, and the critical receptors can be defined to more specific components within the biosphere site itself. We hope much of the research that is going to be conducted as part of the Man and Biosphere program will allow for identification of components within each of the Biosphere Reserves which could be considered critical receptors.

The question now becomes what environmental components should be monitored. Since one of the critical philosophical underpinnings of the Biosphere Reserve concept is that human activity on these reserves must be minimal, intensive ecological studies, research projects, sampling programs, and so forth are precluded. Consequently, environmental monitoring activities on these sites must be conducted in as nondestructive a manner as possible.

The major items that should be monitored are shown in table 1. Since the atmosphere is a major transport route, it obviously must be monitored extensively. Any surface water within the Biosphere Reserve obviously must also be sampled for the appropriate pollutants. Ground water must be sampled, although the problem with sampling ground water is that usually the aquifer is so much larger than the proposed site of the Biosphere Reserve itself. Soil is a component that should be sampled for a variety of pollutants, particularly those from airborne sources.

The question of biological sampling in a Biosphere Reserve must be carefully considered. Although a great deal of information can be obtained from a biological sampling program, the living part of the reserve must be sampled very sparingly so as not to alter the normal balance of plants and animals. In some cases, the selective sampling of plants and animals can be quite effective in determining the concentration and trends of toxic pollutants in plants and animals. Table 2 is an example of average pollutant concentrations in selected animals and plants collected in background areas.

While the network design is considered, it is necessary to discuss some of the requirements of sampling and what differences in the year-to-year sampling are important for networks to detect. As an example, take the global pollutant, mercury. Research conducted by the U.S. Environmental Protection Agency (EPA) indicates that the global atmosphere is probably the ultimate sink of anthropogenic sources of volatilized mercury. This is likely to become

Table 2--Accumulation of selected heavy metals in biological organisms

Biological organism	Heavy metal (Concentration in ppm)			
	As	Cd	Hg	Pb
Mollusks	--	30	30	4
Bird feathers	0.5	0.01	40	11
Marine plants	30	0.4	0.03	8
Marine fish	11	5	102	10
Crustacea	100	6	2	--
Freshwater fish	40	20	17	--

even more important with the increasing reliance on coal as a major source of energy.

Figure 1 is a diagram of results from a recent research program undertaken by EPA (Rogers 1976). Here, agricultural soils were

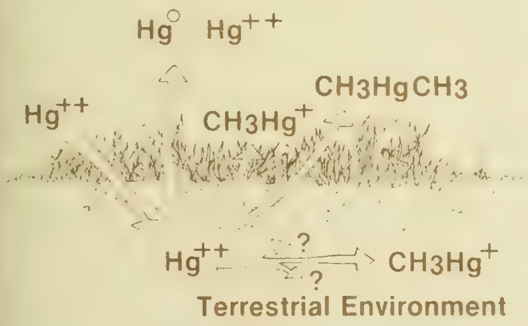

Figure 1.—Fate of mercury applied to agricultural soils. Evolution of methyl and dimethyl mercury from soils takes place within hours after ionic mercury is applied (Rogers 1976).

amended with ionic mercury. They were then extracted and analyzed for the presence of methylmercury. As figure 1 shows, methylmercury compounds are rapidly evolved from the soil surface back into the atmosphere. Similar research on mercury in plants (Gay 1976) has indicated that the plants themselves are capable of methylating mercury. Very recent research has tentatively indicated that dimethylmercury has been given off by plants grown in hydroponic solutions containing ionic mercury. In addition to this, a field monitoring program around known mercury point sources has been conducted (Crockett and Kinnison 1977). Soil and plants have indicated minimal buildups of mercury in areas where mercury was expected to be building up. The conclusions are tentative at this time, but they seem to indicate that one of two things is happening: (1) Methylmercury and other forms of mercury released to the atmosphere are being taken up by mammalian systems living in the area, or (2) mercury is being redispersed into the atmosphere.

Another important consideration is the number of samples to be collected to achieve the desired level of precision. Figure 2 shows the curve for mercury residues in soil which illustrates the problem that we still have to face when sampling Biosphere Reserves. For example, notice that up to about a 10-percent sampling error, a relatively small increase in samples results in a rather large increase in precision. Beyond the 10-percent sampling error, i.e., approaching a 5-percent sampling error, the numbers of samples required to achieve the additional precision are rapidly becoming prohibitive. Note that at 50 samples of soil, there exists a sampling error of approximately 13 percent. At 100 samples, the sampling error has only been decreased to 9 percent and at 200 samples, it has only been decreased to 7 percent.

Although one expects different variance estimates of mercury residues at various Biosphere Reserves, one can still expect that a reasonable ball-park estimate for a 10-percent level of precision is going to require at least 50 different soil samples.

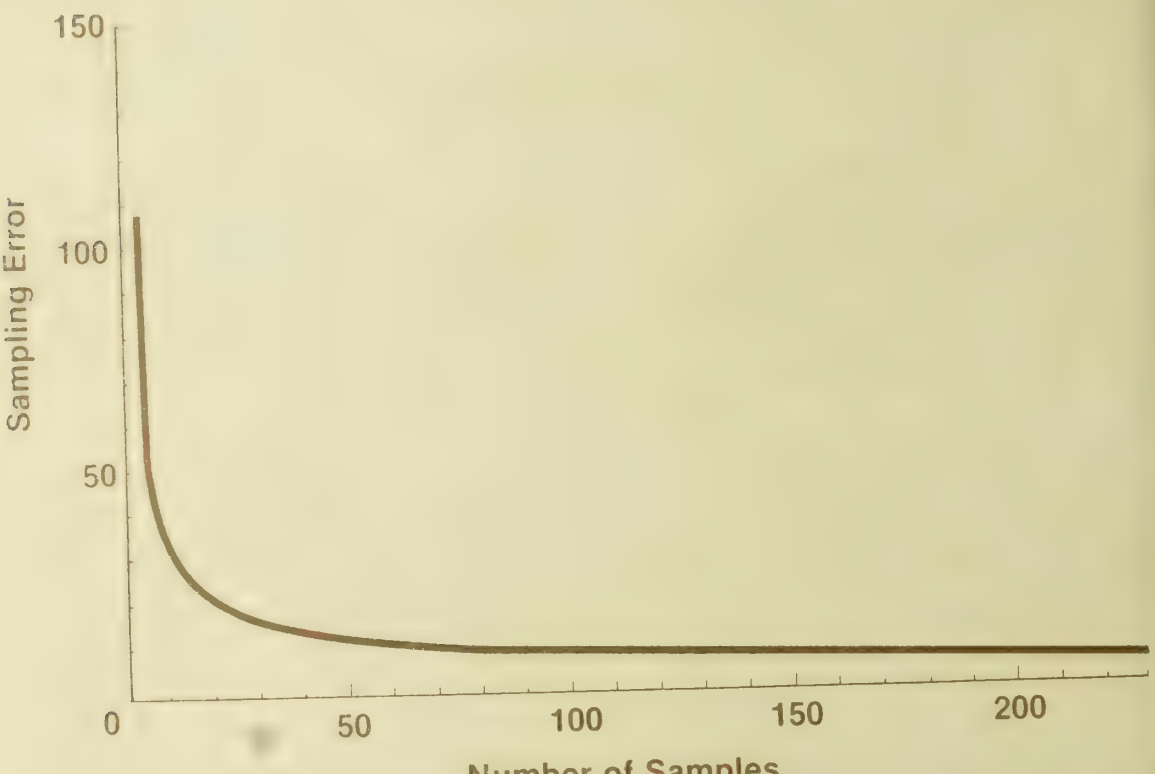

Figure 2.—Curve showing relationship between sampling error and number of samples for mercury residues in soil.

Figure 3 shows similar data for *Gutierrezia*, a common desert plant, which shows very similar results to soil. One needs at least 50 samples of the plant to achieve better than a sampling error of approximately 13 percent

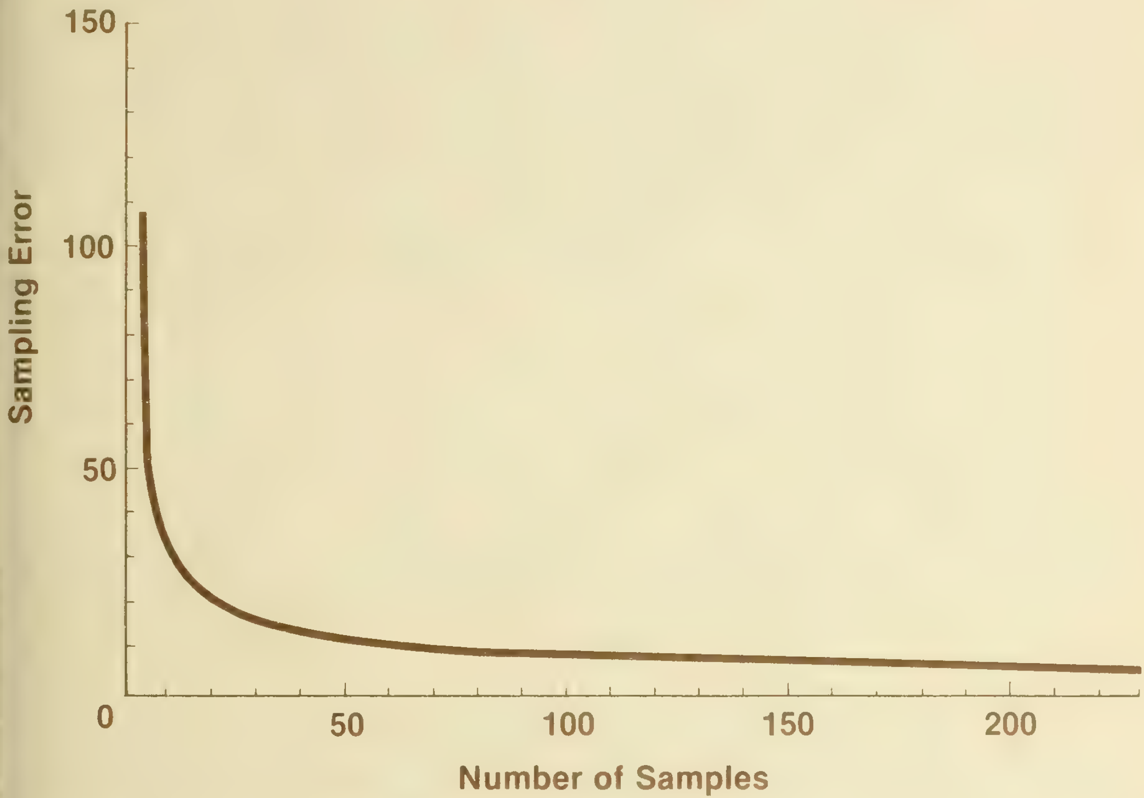

Figure 3.—Curve showing relationship between sampling error and number of samples for residues of mercury in *Gutierrezia* spp.

The question then becomes somewhat simplified. For example, what differences in mercury concentration are you trying to detect in the annual or semiannual samplings? Can one reasonably expect the background levels of mercury to change by 10 percent each year? Are they ever likely to change by 5 percent a year? Figure 3 shows that after a 5-percent sampling error, the slope of the curve becomes practically zero. Similar curves can be generated for other pollutants.

Another thing that must be considered when establishing a Biosphere Reserve is the inventory of existing biological communities. The inventory must be accomplished, of course, in a way which is not damaging to the existing communities. This problem is greater with animal communities than with plant communities.

There are other techniques for assessing changes in ecological systems, including species diversity indices, indices of association and so forth. All of these depend on some form of sampling, some form of counting, and are, therefore, going to have to deal with inherent variability. Jenkins (1971) makes a compelling case for using biological monitors, indicators, and sentinels. Although there is some indication at this time that they have limited usefulness, there is agreement with the statements put forward in the GNEM (Ad Hoc Task Force on GNEM 1970): "We have sought diligently for universal indicators of the biological state of the globe, and have essentially failed. We can, and have, identified many candidates for the particular monitoring purposes in particular locales, but the diversity of life forms, the multitude of habitats for various combinations of species, and the intricately complex interactions among species--to say nothing of their interactions with widely-ranging climates and surroundings--all these features appear to preclude a few simple indicators of "how goes it" among the earth's living inhabitants. This state of affairs also emphasizes the presence--at least in the natural biological--of a significant stochastic component in such ecological measures as species diversity. This essential uncertainty in the natural ecological condition of any particular habitat or biome is the background noise against which observed ecological changes must be judged. Except for extreme changes which completely overrule natural selections and survivability, we are only beginning to perceive the combinations and permutations of life forms which may obtain under otherwise similar environmental conditions."

SPECIAL CONSIDERATIONS

In addition to the collection and analysis of environmental samples, there are presently a number of new instrumentation techniques which have a great potential for nondestructive measurements of the state of the environment as influenced by pollutants. Some of these are as follows:

1. Some of the new techniques of remote sensing from satellites offer an excellent method for ecological research as related to pollutant problems especially as a complement to ground-based networks. With an increase in resolution, the earth resources satellites could provide a continuous overview of the Biosphere Reserves.

2. It is now possible to measure a number of physical and chemical parameters by airborne platforms. Presently, both fixed and rotary wing aircraft routinely measure pollutants such as CO, O_3, CO_2, SO_2, NO, NO_2, suspended particulate matter, and hydrocarbons as well as temperature, humidity, and particle count and distribution.

3. The feasibility of employing remote sensing techniques using high-altitude aircraft are being tested in the following areas:

   a. Detecting stress in vegetation through the use of laser fluorosensing techniques.

b. Measuring water quality, particularly dissolved organics using laser-induced fluorescence emissions.

c. Measuring O_3, SO_2, and CO through the use of active laser-lidar systems.

d. Measuring sediment in water, chlorophyll and biological distribution using multispectral techniques.

e. Measuring energy-related pollutants and effects using overhead remote sensing and photographic techniques.

f. Identification and concentration of selected hazardous substances in water bodies using multispectral scanning techniques.

Such systems would permit to a large extent the rapid monitoring of Biosphere Reserves on a noninterference basis.

4. There are a number of new multielement or multicompound analytical techniques which are accurate, reproducible, automated, and becoming available worldwide. Some of these include energy dispersive x-ray spectrometry, isotope Zeeman atomic absorption, spectrophotometry, plasma emission spectrometry, and gas chromatograph mass spectrometry.

5. Studies are underway to develop and evaluate existing biological indices as environmental monitoring tools. There are probably a number of indices available which must be tested for adequacy before they can be used in an operational monitoring program.

6. Another area which should be considered as a possible monitoring technique is productivity measurements. Traditional productivity measurements have involved the clipping and removal of vegetation on plots. This technique would be disadvantageous for Biosphere Reserves because of its destructive nature. Therefore, one should pursue the possibilities of direct field measurements of various physiological parameters that can be used as monitoring tools to estimate productivity on a site. They also allow the use of relatively small biological samples and thereby minimize impact to local biota. This raises interesting sampling problems which must be dealt with concerning representative samples. The smaller the sample collected, the less the chances are that it is representative of the population from which it was taken.

Finally, it is necessary to establish a sample bank. Particulate, soil, plant, and animal samples should be collected in sufficient quantity to permit the preservation of at least half of the sample. In many cases, pollutant problems exist which are not presently recognized, or for which proper methods and instrumentation are not perfected. In addition, a portion of many samples can be used to intercalibrate laboratories.

Much work must be done to optimize methods for preserving and archiving environmental samples. For some samples, simple dehydration is adequate, whereas for other samples which may be used for organic analysis, quick freezing, followed by sealing in an inert atmosphere, may be necessary.

In conclusion, an intensive study of the Biosphere Reserve is highly desirable if not mandatory. Although there are many factors to be considered, a meaningful monitoring program can and should be initiated without delay.

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Some Basic Principles Concerning Biological Response to Environmental Change

by

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The ability to respond to environmental change is a basic characteristic of all known living systems. Although the types of environmental changes involved and the nature of the responses elicited can vary greatly with respect to time, space and other variables, there are some basic principles which can be applied to facilitate our understanding of the relationships between these processes at any or all levels of biological organization. An understanding of such principles is basic to the design of monitoring and/or research programs for Biosphere Reserve areas. Moreover, a basic understanding of the principles of biological response to environmental change will aid in critically assessing and eventually predicting the impacts of man's technology on ecological systems.

Our discussion of these matters is organized into three main components: (1) the basic principles of environmental change, (2) basic principles of biological response, (3) problems and procedures involved in assessing both of the above as well as their collective interaction. In considering such assessments, emphasis will be given to guidelines for the development of basic research efforts for providing useful and testable hypotheses concerning environmental change and biological response in areas eventually to be designated as Biosphere Reserves. The basic features of these component approaches and their collective interactions are outlined in figure 1.

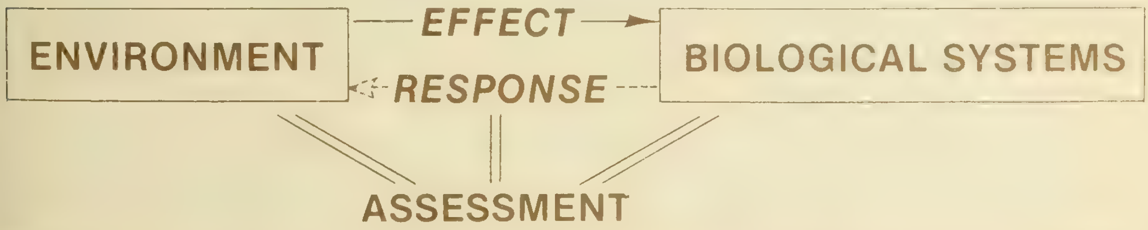

Figure 1.—Schematic representation of the assessment of the environment, the biological system and their interactions.

The concept of "environment" may be most usefully defined, for purposes of this discussion, relative to levels of complexity of organization of the natural world. The consideration of a gradient in levels of complexity of organization has been used in a fundamental sense to both establish the basic principles of ecology (Odum 1971) and to define the word "ecology" (Brisbin 1974). In this sense, the concept of "ecology" often simply defined as "the relationships between organisms and their environment," is simply expanded to the general case by defining the word "environment" as those levels of organization other than the one which is under consideration (fig. 2). This definition of the word "environment" may be applied to any level of biological organization. For example,

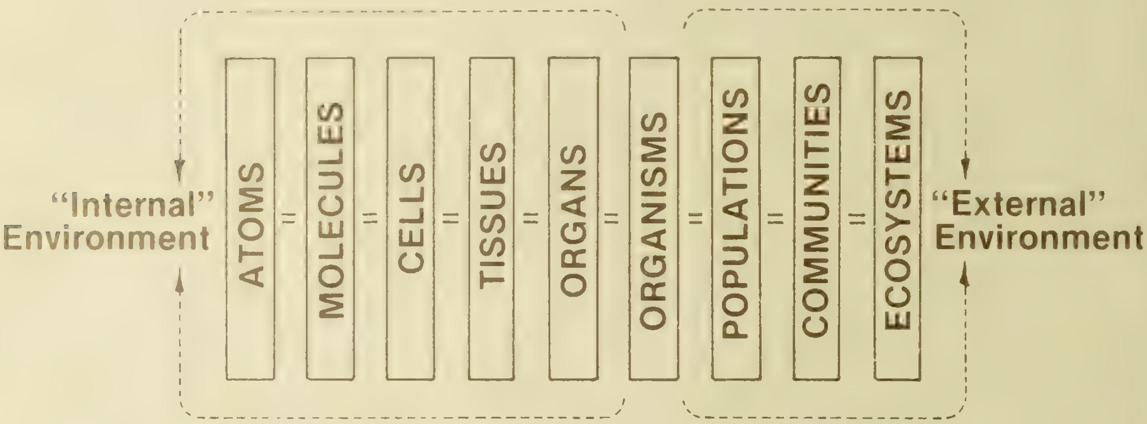

Figure 2.—Consideration of the concept of "environment" as being those levels of organization of the natural world other than the one under consideration. An individual organism, for example, has both an internal and external environment, consisting respectively, of less complex and more complex levels of organization (after Brisbin 1974).

a cell in a human liver, like a deer in a forest, has both an internal and external component to its "environment," consisting of those levels of organization which are, in each case, less and more complex than the particular level of organization being considered. The concept of levels of complexity of organization of the natural world will be used in this discussion both to define the concept of "environment" as well as to provide a frame of reference for a later discussion of the concept of biological responses to environmental change.

Three characteristics are important in relating biological response to environmental change: (1) *Magnitude* of change, (2) *Pattern* of change, and (3) *Rate* of change. Pattern and rate deal with the problems of relating and defining the processes of environmental change in terms of space and time. Similar considerations of both time and space should also be incorporated into analyses of biologica

responses and the procedures for the assessment of both environmental change and biological response.

Of the three main characteristics of environmental change outlined above, it is undoubtedly those characteristics of rate which are the most important in determining the exact nature and extent of consequential biological response. Moreover, as will be discussed later, it is also the characteristic of rate which will prove to be the most important feature in distinguishing the consequences of man-induced environmental change from those resulting from natural processes. Living systems, whether cells, individual organisms, populations, or entire communities, are usually capable of adapting to and thereby surviving most environmental changes if such changes occur gradually.

The extremes of temperature endured by living populations of microorganisms and various invertebrates inhabiting thermal springs and polar icecaps attest to the magnitudes of environmental change to which organisms can adapt through evolutionary processes over extended periods of time. Even small, rapidly occurring environmental change, however, may have profound impacts on organisms and populations. Frequently, changes in some environmental parameter such as temperature or humidity, which may only prove detectable in terms of the computation of long-term seasonal means or, for example, average daily maxima, may have profound effects on the breeding biology, growth rate, or other vital aspect of an organism's life history or other biological characteristics (e.g., Bryant 1974).

Studies of temperature tolerance in various organisms illustrate the importance of rate of change in determining consequential biological response. In particular, several studies (e.g., Brett 1970, Coutant 1972, Martin and Gentry 1974) have shown that exposure of certain organisms to gradual increments of temperature will result in acclimation to higher temperatures. Acclimation allows such organisms to endure a greater degree of heat stress than would have been possible if such a temperature increase had been delivered more suddenly without the preceding period of gradual acclimation.

At higher levels of biological organization, the related process of adaptation which occurs in response to gradual environmental change over relatively longer periods of time, has frequently been shown to allow populations and/or biotic communities to tolerate environmental changes of a magnitude that would not have been possible if such changes had occurred rapidly. Long-term geologic and climatic alterations are well-known examples of environmental changes which have occurred at a sufficiently slow rate to allow various populations enough time to make the evolutionary adjustments which were needed to survive under the new environmental regime. For example, small sustained increases in swamp water levels in certain parts of the Southeastern United States have apparently contributed to the death and destruction of entire cypress tree communities following the introduction of production reactor effluents into such areas (Sharitz et al. 1974). In these very same areas, however, much more drastic fluctuations in water level have occurred over geologic time, as the sea level of the Pleistocene Ocean gradually fell,

exposing the coastal terraces and sea floor as the present day southeastern coastal plain. Through this latter process, however, the more leisurely pace of environmental change (i.e., change in water level) allowed orderly successional changes in plant communit structure to keep pace. Mortality responses of the resident communities were undoubtedly different from those produced by reactor-induced increases in water level, despite the much greater magnitud of the changes involved. In systems such as the Florida Everglades however, fluctuating water levels are prerequisite to the maintenance of stability in the biological community (Kahl 1964). Thus, certain kinds of environmental changes may actually be stabilizing rather than disruptive to the community. In such cases, the stabil ization of environmental conditions may result in significant alter tions of community structure and function.

Besides being one of the most important aspects determining the ability of various living systems to survive environmental change, the concept of time or rate is also one of the most important features distinguishing between so-called "natural" environmental changes as opposed to those which have been created by man's civili zation and technology. In certain respects, the environmental chang resulting from many of man's activities do not really differ in typ or mode of action from naturally occurring environmental changes. One difference is that man-induced changes generally occur over a much shorter period of time. The process of floral and faunal species extinctions, for example, has commonly occurred throughout geologic time. There has recently been a documented increase in th rate at which species, particularly large vertebrates, have become extinct as a result of the activities of man. Moreover, man-induce environmental changes can act synergistically or concurrently with natural processes and further increase the effects of such changes. Studies by Krantz (1970) and Mosimann and Martin (1975) have demonstrated, for example, how increased predation pressures from Paleo-indians could have interacted with natural mortality factors to produce massive Pleistocene extinctions amongst many species of lar game mammals inhabiting the North American continent.

The study by Mosimann and Martin (1975), moreover, emphasizes th importance of spatial considerations (pattern) and the interaction of pattern and rate in producing the observed extinctions of many o the large Pleistocene game mammals by early man. Had either the pattern or rate of human exploitation and hunting differed, it is possible that some biological response other than massive mammalian community extinction might have been observed, thus resulting in a vastly different mammalian fauna in present-day North America. In still other cases, rapid environmental changes produced by human activities may produce biological responses which are mediated through normal evolutionary processes most of which normally proceed at a more leisurely pace. The well-known case of industrial melanism is an example of just such a situation (Kettlewell 1956). Artificial selection by man through the process of domestication (Brisbin 1974) suggests one of the most extreme cases of the respon of evolutionary process to environmental changes which have been instituted at a greatly accelerated rate as compared to more natura situations.

In many of the preceding examples, our focus has been on a complex of environmental factors such as climate. In a biosphere reserve it will be necessary to decide to measure a series of specific variables. It is impossible in this paper to list and rank all of the variables that should be measured at each site. This is partly because the objectives may be site specific and, thus, the rank order will vary accordingly. Nevertheless, we have listed a number of variables that should be addressed as potentially important and should be considered in regards to any long term research or monitoring program (table 1). The frequency of measurement should vary according to the magnitude of short term fluctuations. Extremely static variables should be measured less frequently. Certain variables can be easily recorded on a continuous basis with available instrumentation.

Certain Biosphere Reserves will require special environmental measurements because of their unique physical characteristics (e.g., deserts or glaciated areas). The mass and speed of glaciers are examples of this type of problem. In general, this type of variable falls into the relatively stable category in which small changes may have profound effects on all levels of biological organization. Some of the environmental measurements will have regional significance; and an attempt should be made to determine the extent to which this may be true, perhaps by correlational analysis.

The environment has both physical and biological components. An ecosystem is the biological community plus its physical environment and their interactions. In addition, a biological response can be viewed as an environmental change depending on the reference point of interest within the level of organization studied. For this reason it is not practical to completely separate biological responses from environmental changes, but each can be discussed separately as a class of phenomena. Biological response can be measured at any one of the various levels of organization (fig. 2). For our purpose we will be concentrating on the individual, population, and community levels. Responses at lower levels are frequently seen at higher levels of organization, although they may be expressed in a different way.

A shift in environmental conditions can elicit a variety of responses in the organisms (table 2). The response(s) triggered will depend largely on the type and magnitude of environmental changes and the organism's "limits of tolerance" to the specific environmental variables which have been altered (Odum 1971). An organism's genotype is a product of generations of natural selection and evolution. Hence, each individual is adapted to specific sets and ranges of temperature, oxygen concentrations, moisture, chemical concentrations, and other environmental parameters.

A shift to a different set of environmental conditions can have varying effects. At very low levels of intensity, an environmental perturbation such as pollution may have effects that are measurable only as increases in concentrations of the pollutant in the body of the organism. At higher levels of stress, changes in an individual's behavior patterns may become apparent. The growth rate of an organism

Table 1--Examples of potentially important environmental variables to be measur[ed] as part of baseline or monitoring studies[1]

Variables	Frequency of measurement[2]
I. Climatic	
A. Temperature	Continuous
B. Relative humidity	Continuous
C. Windspeed and direction	Continuous
D. Turbidity	Frequently
E. Suspended particulate matter	Frequently
F. Rainfall	
1. Pollutant concentrations	Frequently
2. Major cations and anions	Frequently
3. pH	Frequently
4. Amount	Continuous
G. Barometric pressure	Continuous
H. Solar radiation	Continuous
II. Hydrologic	
A. Water discharge	Continuous
B. Water levels	Frequently
C. Height of water table	Frequently
D. Temperature	Continuous
E. Turbidity	Frequently
F. Suspended sediment	Frequently
G. Major nutrients	Frequently
H. Trace elements	Frequently
I. Specific conductance	Continuous
J. Organics	Frequently
III. Soils	
A. Physical characteristics	Infrequently
B. Water content	Frequently
C. Major nutrients	Infrequently
D. Trace elements	Infrequently
E. pH	Frequently
F. Organics	Frequently

[1]Only the physical aspects of the environment are considered in the table.

[2]Frequently means a greater than daily time interval between measurements; infrequently means at least 1 year.

Table 2--Categorical responses of 3 levels of biological organization to environmental change and parameters for their measurement and/or detection

Level of organization	Category of response	Variables	Sample references [1/]
Individual	Structural	Gross morphology	Valentine et al. 1973
		Microanatomy	Hinton et al. 1973
		Chemical composition	Zeller and Finger 1971, Ratcliffe 1975
	Functional	Physiology	Cairns et al. 1973
		Behavior	Cairns et al. 1973, Poels 1975
		Development	Nelson 1974, Christy et al. 1974
Population	Structural	Abundance	Ehrlich et al. 1972
		Age composition	Hassler 1970
		Sex ratio	Klein 1965
		Genetic structure	Bonnell and Selander 1974, Selander 1976
	Functional	Reproductive rate	Ferens and Murphy 1974
		Survivorship	Pough 1976
Community	Structural	Species diversity Indices	Wilhm and Dorris 1968 Cairns et al. 1973, Haedrich 1975
		Percent similarity	Haedrich 1975
	Functional	Productivity	International Biological Project Handbooks

1/ References are examples rather than all inclusive.

can be enhanced or diminished by a change in its environment. Environmental stress may cause abnormal development and growth (Valentine et al. 1973). If perturbation results in a shift of one or more factors to levels outside the individual's tolerance limits, the organism must either emigrate or die.

A species population may respond to an environmental change with an increase, decrease, or no change in numbers or quality of individuals. Assuming movement in and out of a population to be approximately equal, then differential reproduction and mortality are the immediate reasons for change. Density, reproductive rate, and survivorship are important variables for study. Since these variables do show considerable change over short time periods, it is necessary to take a long range view to detect significant trends related to the overall health of the community. Certain species can be more easily studied than others in regards to these variables. Since our view in a Biosphere Reserve has to have a strong wholistic perspective and because it is not possible to study every species, a series of species should be chosen for study that represent different functional components of the system (e.g., carnivores vs. producers).

An additional criteria might be to choose "potential problem species" whenever possible. A "potential problem species" being one that might accumulate pollutants and become part of the food chain of man.

Quality of individual organisms may also change through time. For example, gene frequencies appear to fluctuate on an annual or longer term basis (Pimentel 1961, Krebs et al. 1973, Smith et al 1975). These types of changes can be especially important in judging the health of the biotic community and must be measured to determine the adequacy of the biosphere reserve concept. Let us suppose that one of the reserves is not sufficiently large to maintain genetic diversity either within or between species. A decrease in species number would be indicative of this situation, but decreases in genetic variability within species may be the earliest warning of restricted gene pools. Survey methods now exist for such measurements to be made on a variety of species (Smith et al. 1976). Other indices of population quality might be related to age structure, movement patterns, dispersion, flow of materials, and body composition and condition. There are many technological problems in measuring these variables, but in many cases they are species specific and will not be covered here.

The presence or success of certain species populations has long been used as an indication of environmental conditions. The occurrence of a species indicates that the environment is suitable for that species. If the environmental requirements for existence of a particular species are well-defined and relatively restricted, the presence of that species indicates the general nature of the environment in which it occurs. This is the indicator species concept. While the concept of the indicator species has been widely employed, it has serious, inherent limitations. These have been discussed in detail by Gaufin (1973), Patrick (1973), Cairns (1974) and Wuhrmann (1974). A major criticism of these authors is that environmental conditions other than the specific variables of interest may prevent the occurrence of an organism. In addition, the presence of an organism can be precluded by factors other than environmental suitability. For example, the species may not have had the opportunity for colonization of the area. When species are found for which detailed tolerance information is available, the information should be used.

Recently, biological assay techniques have emerged which utilize characteristics of a population other than its presence or absence to assess environmental changes. Valentine et al. (1973) used fluctuating asymmetry of three marine fishes as a measure of environmental stress resulting from pollution. Fluctuating asymmetry was defined by Valentine et al. (1973) as random deviation from perfect symmetry of any bilateral character and was thereby utilized as a measure of environmental perturbation. Certain species populations may also be employed as indicators of heavy metal contamination of the environment. For example, total mercury concentrations in tissues of piscivorous fishes are considered the best indicators of mercury pollution in aquatic systems (Zeller and Finger 1971). Similarly, analyses of lead concentrations in mosses and grasses provide a reasonable indication of changing atmospheric lead content

(Ratcliffe 1975). In addition, it may be possible to assess the concentration of a contaminant in one component of community and predict its concentration in some other component (Anderson et al. 1973). The use of organisms as bioassays or environmental pollution or stress is currently an area of intensive and promising investigation.

Multispecies responses to environmental changes are manifested at the community level. The observed responses can be structural, functional, or both. A structural response implies a shift in species composition or relative species abundance in the community. A functional response involves changes in features such as productivity and rates of nutrient transfer and energy flow. The structural attributes of communities have traditionally received more attention from ecologists than the functional aspects (Odum 1962). This is largely because the study of function is more difficult than the study of structure. In addition, ecologists have only recently begun to appreciate the importance of understanding rates as our view of nature has evolved from a static to a dynamic one.

Biological communities typically undergo natural changes in structure during ecological succession (Odum 1969). An environmental disturbance or perturbation results in a shift in the species composition of the community, usually to an earlier successional stage. For example, natural disturbances such as fire and windstorms revert forest vegetation to earlier stages of succession (Loucks 1970, Wright 1974). In aquatic and marine plankton communities, changes in the algal flora generally accompany temporal shifts in availability of nutrients (Patrick et al. 1969, Hutchinson 1973, Welch et al. 1975, and Pomeroy 1975). The nutrient enrichment or eutrophication of lacustrine environments results in increased standing crop of the phytoplankton community (Bachmann and Jones 1974, Schindler and Fee 1974, Welch et al. 1975) and a shift in dominance from diatoms and green algae to blue-green algae (Hutchinson 1973, Welch et al. 1975).

An additional community response to perturbation or stress is a reduction in species diversity (e.g., Paine 1966, Tsai 1973, Haedrich 1975). Hence, many investigators favor use of diversity measures in the biological assessment of pollutional stress (Cairns 1974, Haedrich 1975). A diversity measure, however, indicates nothing of the species composition of a community. Changes in species composition of a community can occur without corresponding changes in diversity. Haedrich (1975) has overcome this problem by using a measure of species overlap (percentage similarity) in conjunction with a diversity function to assess spatial and temporal shifts in community composition. This results in a powerful assessment of environmental pollution when seasonal changes in diversity and species composition are considered. A recent review of species diversity measures and the assumptions underlying their application has been presented by Peet (1974).

Natural succession of biotic communities is accompanied by functional as well as structural changes. For example, Loucks (1970) observed increases in both productivity and diversity during succession

of temperate forests. After the climax was reached, both diversity and productivity were diminished. There are many general hypotheses concerning functional changes in communities during succession (Odum 1969). Most of these have had little study, however, and many are subjects of considerable debate.

Altered productivity frequently results from an environmental disturbance or perturbation. Addition of toxicants may decrease community productivity (Whitworth and Lane 1969), whereas increasing the supply of limiting nutrients to a community will increase productivity (Schindler and Fee 1974, Tamm 1975). The casual factors altering productivity may initially be subtle and not readily appare For example, increased productivity of aquatic communities can resul from remote manipulations or disturbances within the watershed which result in increased rates of nutrient supply (Bormann et al. 1974, Dillon and Kirchner 1975).

A new view of natural disturbance and community succession is beginning to emerge in the management of large, forested wilderness areas. This view is that most temperate forests may not have reache true "climax" because of recurring natural perturbations (mainly fir which periodically reverted the community to earlier successional stages (Loucks 1970, Wright 1974). Under man's protection fires are suppressed, however, and the frequent natural perturbations, however, under which these communities developed are largely prevented. Continued protection allows persistence of a climax state and accompanying decreases in community diversity and productivity. Loucks (1970) and Wright (1974) convincingly argue that these systems should be allowed to undergo periodic natural perturbations to maintain the diversity and productivity of the communities. They suggest that elimination of natural perturbations may be the most disturbing effect of man on wilderness areas.

The first attempt at quantitative definition of various types of relative stability was made by Lewontin (1969). Webster et al. (1975) more recently defined two components of relative stability, resistance and resilience. Resistance is the ability of a system to resist displacement. Resilience is the ability of a system to return to a reference state once displaced. Since we are concerned here with biological responses to environmental changes, our focus will be on the resistance component of stability.

Stability of ecological communities has traditionally been associated with species or food web diversity. In an extensive review of the literature in this area, however, Goodman (1975) concluded that the theory of diversity-stability relationships in ecology is without substantial empirical or experimental support. What then, are the attributes of a community which determine its resistance to perturbation? The following discussion will, for two reasons, center on studies of nutrient cycles. First, the activities of man have had a marked effect on cycles of elements at both local and global scales. Man-caused alterations in rate of nutrient supply are common in nature. Second, as Duvigneaud and Denaeyer-De Smet (1975:151) state, "Mineral cycling is one of the most important parameters in the analysis of ecosystems,

because mineral elements, as many as energy and water, are essential to maintain the continuity and stability of these systems."

Pomeroy (1970 and 1975) associates relative stability with availability of nutrients or size of nutrient reserves. After comparing stability and nutrient regimes of four marine systems, coral reefs, oceanic plankton communities, subtidal eelgrass (*Zostera*), meadows and cordgrass (*Spartina*) communities, Pomeroy (1975) concluded that the relative stability of these four communities was much more easily related to availability of essential elements than to species diversity. Applying computer simulation techniques, Webster et al. (1975) examined stability of model ecosystems and reached similar conclusions. Model resistance to perturbation was positively correlated with size of nutrient storage compartments.

Observations on oligotrophic lakes provide additional empirical support for Pomeroy's hypothesis. By definition, nutrient pools in oligotrophic systems are small. Rate of primary production by the phytoplankton community during daylight hours is closely coupled to changes in the rate of supply of some limiting nutrient(s). Whole-lake experiments by Schindler and co-workers involving fertilizer additions to Canadian lakes have clearly shown that addition of phosphorus alone is sufficient to cause eutrophication (Schindler and Fee 1974, Schindler et al. 1975). Once made eutrophic by fertilization, the phytoplankton community is much less responsive to additions of nutrients (Schindler and Fee 1975, Schindler et al. 1975). Rate of phytoplankton production in culturally eutrophied lakes may ultimately be dependent on rate of influx of carbon dioxide from the atmosphere. Hence, phytoplankton production is most rapid for 2-3 hours following sunrise and undergoes a strong duirnal cycle in nutrient enriched lakes (Schindler and Fee 1975, Schindler et al. 1975).

Further investigations of nutrient cycles will undoubtedly provide additional insights concerning the stability of ecological systems. The importance of nutrient cycles will need to be determined for communities within the Biosphere Reserves.

As pointed out above, changes can occur at all levels of organization but must be documented. The general problem of assessing changes in a biological system through time and space has several facets. Of primary importance is the variance of the variable and the desired confidence interval for the measurement. As the confidence interval gets smaller or the variance larger, the number of replicates increases dramatically (table 3). Under certain circumstances the number of replicates could be excessively large. The desired confidence interval should be set *a priori* but is usually increased when the variance is found to be large relative to the mean. This results in a reasonable sampling schedule given the financial and personnel limitations inherent in most programs.

These considerations are further complicated when we are interested in documenting a spatial pattern or rate of change. Multiple samples through space or time are necessary, and the sampling interval is very important. With a good design and knowledge of the

Table 3--The number of samples necessary to achieve a certain confidence interv (C. I.) as a function of the coefficient of variation (C. V.) of the data. The C. V. is equal to the standard deviation (S) divided by the mean ($\bar{X}$) times 100 while C. I. equals two standard errors expressed as a percentage of the mean or $(2S/\sqrt{N}/\bar{X})\cdot 100$, where N is the number of samples

Confidence interval	Coefficient of variation*					
	5	10	25	50	75	100
1	100	400	2,500	10,000	22,500	40,000
5	4	16	100	400	900	1,600
10	1	4	25	100	225	400
25	1	1	4	16	36	64
50	1	1	1	4	9	16
75	1	1	1	1	4	7
100	1	1	1	1	2	4

*Samples of one cannot be used to calculate a confidence interval and shoul be used only as an indication of the low number of replicates required.

process, the rate function can be calculated with as few as six we chosen samples. Of course fewer samples may suffice but usually m than six samples would be required. If the pattern is a spatial mosaic, then replication on a site and increased distance between sampling locations will allow efficient partitioning of the varia If appropriate community variables are measured at each site, the correlation and/or regression analyses become possible resulting in statistical statements concerning intra-community relationship Ratios for the distribution of trace substances across trophic le may be fairly constant in a variety of communities (Anderson et a 1973). Changes in these ratios may be important indicators of sh in trophic functions.

Our view of biological response must not be naively simple. Ecology is complex, and data collecting schemes should be designe to evaluate the importance of interaction and possible synergisms between variables in addition to their simple effects. This nece sitates the use of multivariate statistical methods in addition t more complicated analysis of variance models. Lastly, all effect should not be expected as changes in mean values of some biologic response. For example, certain environmental changes may result disruptive selection, which would be expected to change the fre- quency distribution and increase the variance of the data. Trace contaminants are probably not normally distributed in biological systems (e.g., Pinder and Smith 1975) and calculation of the fo of the frequency distribution draws attention to the first four moments of the data (mean, variance, skewness, and kurtosis). Th form of a distribution may change under different environmental c ditions or at different levels of biological organization (Pinder and Smith 1975).

The plan for collecting data in a Biosphere Reserve must be based on an understanding of techniques for calculating confidence intervals and changes that might be expected just as a result of the management of a reserve. For example, exclusion of fire could have profound effects and alter successional patterns in the reserve. Effects due to management of the reserve need to be delineated from other effects that might be due to the general deterioration of the environment either on a local or regional scale. Unambiguous assessment of biological change as an indication of environmental quality could be essential to man's survival in the face of expected technological impacts on the earth.

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Biosphere Reserves—Strategies for the Conservation and Management of Forest Gene Pool Resources

by

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INTRODUCTION

It is generally agreed that Biosphere Reserves offer a unique and often the only means of protecting, conserving, and maintaining a large diversity of ecological systems of varying sizes and complexities for current and future studies. Biosphere Reserves offer the ecologist a proven baseline, a reference point, on which to develop concepts related to the dynamic changes associated with evolving natural systems. In fact, most ecologists consider Biosphere Reserves as enlarged protected natural systems, and such areas are needed for research if we are to develop an understanding of the functioning and productivity of the large complex ecosystems.

To foresters who are interested in the maintenance as well as the long-term genetic improvement of the forest crop, Biosphere Reserves offer both a new opportunity in advancing the science of forest tree improvement as well as a much needed built-in safeguard for maintaining genetic diversity of forest trees which are subject to both extensive and intensive forest management.

Many different events during the last few years strongly suggest that forest geneticists must be concerned in ensuring an adequate and broad genetic base for forest trees if forestry is to avoid the errors of genetic erosion all too common in general agriculture (Barber and Krugman 1974, Maini 1973, Yeatman 1972). Over the centuries we have seen the risks that are involved when crops are built on a narrow genetic base. Outstanding examples include the potato blight and the subsequent potato famine in Ireland in the 1840's, the pear decline on the West Coast of the United States during the 1960's caused by a susceptible root stock, the common wheat rusts wherever wheat is grown, and most recently, the corn blight in the eastern United States in 1970 (National Academy of Sciences 1972, Barber and Krugman 1974).

Worldwide utilization of forest resources as well as forest land conversion for agriculture and urbanization are increasing. In most countries forest practices are becoming more intensive, and few forest stands will remain untouched. In many countries the native forests are being removed at a rapid rate and are often replaced by exotics or non-local reforestation stock with an indiscriminate mixing of often unrelated gene pools during reforestation (Maini 1973). This further erodes our ability to recover stable

and well adapted parental lines. It is necessary to maintain ancestrial genotypes as well as a broad genetic basis for future selection and breeding programs. Mixing of natural gene pools must be restricted (Yeatman 1972). Who knows what genotypes will be needed in the future? We must minimize the dangers of possible permanent genetic losses in a forest system.

Our strategies for meeting these issues must be based on a clear understanding of the genetic variation associated with forest trees. In addition, it must clearly be understood that forestry problems associated with maintaining a genetic base are not identical to general agriculture. Proposed solutions certainly will vary from those now being attempted in horticulture and agronomy (Hawkes and Large 1973).

GENETIC VARIATION IN FOREST TREES

It is generally recognized and accepted that forest trees have evolved inherent adaptations to a series of environmental factors at the site where they grow (Callaham 1970, Yeatman 1972). Research in the last 100 years has clearly shown that diverse environments throughout the range of a tree species leads to a genetically variable species. Similarly, widespread species tend to be more variable than restricted species. Often patterns of inherent variation parallel patterns of environmental variation (Callaham 1970). Likewise, races of a species growing in different climatic regions may differ in inherent adaption to environmental factors. Still, limiting factors generally are not always the same for cohabiting species (Callaham 1970).

More recent studies show that for native species local seed sources are best adapted but not always the most productive (Callaham 1970). In many areas of the world, however, there is inadequate information about the proper seed source to employ due to a lack of testing; and local seed sources must still be employed. In fact, in the absence of better information, conservative forestry programs are still solely dependent on a local reliable seed source. With provenance research and testing, preferred seed sources are being identified and recommended for use. Often provenance research is conducted to establish the credentials of exotic populations in those locations lacking a sufficient number of commercial species.

It is apparent then that if forestry is to avoid the loss of the original genetic base, strategies must be developed to maintain a reliable and varied genetic reservoir for future improvement, to provide standards for progress in improvement, and to ensure and perpetuate selected large or small populations for future mass seed production (Maini, Yeatman, and Teich 1975; Yeatman 1972). Even if we were only concerned with shortrun situations, the maintenance of the integrity of current populations of selected and proven seed collection areas is a serious problem. This is not an abstract problem to be confronted at some future date. Virtually all nations with active forestry programs are now encountering this problem. We need to assist and offer possible solutions to these difficulties

CURRENT EFFORTS OF FOREST GENE MAINTENANCE

At this point, I hope that I have not left you with the impression that nothing has been done to protect the forest gene resources. To the contrary, various programs are in progress (Barber and Krugman 1974). Among the more common protective methods are:

1. *Seed, pollen, and tissue culture storage.*--Once forest tree material has been selected, it is feasible to maintain certain biological material as seeds, pollen, and more recently, tissue culture by means of various forms of storage--a method which is common to general agriculture. Obviously, when this method is employed, a decision has been made as to what is unique or superior. Our needs often change and so will our selection criteria. This method is also limited in scope since at this time not all material can be stored. Storage obviously leads to a static development in genetic composition since normal selection and evolution is halted (Wang 1975).

2. *Seed stands and plantations.*--A common practice is to set aside selected stands or develop plantations for future seed collection. Essentially, these represent only relatively small areas and can be employed to guarantee only limited genecological groupings.

3. *Seed orchards and arboreta plantings.*--These methods provide a means for maintaining genetic selections. As with storage, these methods are static and assume future needs. They do not permit normal evolution and commonly are relatively small in size.

4. *Research and Ecological Natural Areas, National Parks, Primitive and Wilderness Areas.*--These areas are set up for a variety of reasons, often for recreation purposes. Unfortunately, they are rarely established or managed for maintaining a broad genetic resource which is needed in forestry. They do provide a form of germ plasm conservation and certainly are needed and useful in the broad development of a germ plasm conservation program. Since the major use of these areas often precludes disturbances and commercial activities they are not suitable for mass seed collections and related activities needed in production forestry (Yeatman 1972).

BIOSPHERE RESERVES AS GENE POOL CENTERS

Should the limits placed on Research Natural Areas, or a wilderness not also apply to Biosphere Reserves? No, not if we consider Biosphere Reserves as a dynamic system whose purpose is to meet a number of well defined ecological situations. In the broadest meaning Biosphere Reserves can be used for (a) preservation, (b) conservation, (c) directed management. Thus, a given Biosphere Reserve should include both static and dynamic systems. Obviously, the same portion cannot and should not be used for all purposes.

How then can a Biosphere Reserve be structured to meet the current and future needs of forestry? First, to be effective the Biosphere Reserve must include forest ecosystems which are representative of forest gene pools commonly found in areas where

consumptive forestry is practical and will be practiced. Second, the Biosphere Reserve must be sufficiently large so as to reflect a full range of biological and environmental diversity. Third, it should be possible within the Biosphere Reserves to manage and manipulate given forest ecosystems. Finally, it should be possible to make both small and mass seed collections for consumptive forestry purposes.

It is rather obvious, if Biosphere Reserves are to be employed in advancing the science of forestry, that they must be representative of forests in which consumptive practices are employed. Their selection criteria should include this element whenever possible. Otherwise, studies and maintenance of Biosphere Reserves will become merely an academic exercise in terms of modern forestry.

The gene pool of natural forest population is in adaptive and dynamic balance with a given environment and can only be maintained through successive generations within the environmental context in which it evolved (Yeatman 1972). Since patterns of inherent variation of forest trees reflect patterns of environmental variation, it is essential that as many patterns of environmental variations are included in a Biosphere Reserve system. Thus, their size should reflect the extent of the biological and environmental variation encountered and they must encompass extensive forested areas. The area should also be sufficiently large to minimize the hazard of foreign pollen contamination. Included should be those stands which are highly unique and exceptional in growth and form as well as the typical representative stands of the area. In addition, the sensitive and often unique transition zones of the various species should also be included. Distinct forest tree populations threatened with destruction should be part of the Biosphere Reserve. We desire to "capture" as much of the gene pool as possible.

Many of the current attempts at gene pool conservation are static systems. They are directed at arresting the present rate of evolution, i.e., permit fire control. Similarly, all too often under undisturbed forest conditions shade intolerant species are at a distinct disadvantage and can be eliminated (Maini, Yeatman, and Teich 1975; Yeatman 1972). Yet many of these same intolerant species are a major source of current and future supply of wood and fiber. It should be possible by proper management, i.e., fire, logging, planting, to repeatedly maintain a segment of a Biosphere Reserve in a halted successional sequence.

We noted earlier that there is a serious problem of recovering and maintaining proven seed sources. By permitting mass seed collections, the genecological pedigree of a seed source can be guaranteed which in this day of declining intact gene pools is rather important to modern forestry. In essence, selected portions of a Biosphere Reserve would serve as a tested, reliable, and varied genetic reservoir for perpetuating selected populations for forestry. In fact, certain portions of the Biosphere Reserve should be preserved intact after the initial screening has taken place.

These recommendations for possible forestry uses of the Biosphere Reserves are not in conflict with the general philosophy of the system. To the contrary, the Biosphere Reserve effort is strengthened if the system can meet these forestry challenges in gene pool management.

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Thoughts on the Optimum Size of Natural Reserves Based on Ecological Principles

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Living organisms on the surface of the earth provide a unique source of genetic information unavailable in any other form for human exploitation.

In addition, the association of species into natural communities represents a unique series of coevolved systems representing the functioning of ecological laws which humans must understand in order to determine their ability to be a part of or regulate such systems for human advantage.

Scientists are now asking questions related to the preservation of ecosystems and their component species. Two questions of general interest are, (1) how big must an ecosystem reserve be to maintain its general community and species content integrity, and (2) how many replicates of these communities must we maintain to assure the continuance of all genetic lines.

It is interesting that the answers to these questions probably rest at the intersection of two bodies of knowledge--community ecology and the recently formalized theories of island biogeography (MacArthur and Wilson 1967).

The aspects of community ecology which are of particular interest fall into what might be called the species diversity-stability model. In its simplest form the paradigm predicts that in some manner the inherent stability of a community increases as the count of included species increases.

Such a simple construct of the relationship between these two phenomena is misleading. Whittaker (1975) and Orians (1975) list nine possible meanings of the word stability. Auclair and Goff (1971) indicate several ways to calculate a number representing species diversity. If the computation and definition problems were not sufficient, the correlation itself may not always hold; i.e., some species-poor ecosystems may have a high degree of some types of stability, e.g., the "robustly enduring" simple systems of May (1975).

I define stability as the maintenance of the ecosystem's equilibrium integrity in the face of perturbation. I realize that stability can be due to the diversity of species or the internal organization of the component species, or both. A similar position is expressed

by Van Emden and Williams (1974). In addition, I define species density as the number of species per unit area, and species diversity will include consideration of both abundance and equitability.

With these operational definitions set, let us discuss the problem.

AREAL EXTENT — SPECIES NUMBER

Studies of islands (MacArthur and Wilson 1967) suggest that the number of species/unit area may be approximated by the formula

$$S = CA^{z}$$

where S = number of species on an island; A = island area; C = a parameter characteristic of the particular taxon and archipelago of interest [synonym of *So* in Diamond (1975)]; z = a power assuming values in the range 0.18-0.35 (Diamond 1975) and approximated *a priori* by assuming that species abundances are distributed in a lognormal manner (Preston 1962).

We may use this relationship to infer the optimum size of a nature reserve. If we have a certain number of species, we simply calculate the area necessary to maintain them. The obvious point of difficulty is that the calculation requires estimates for the values of z and C.

The lognormal approximation for z is certainly reasonable considering the plethora of data suggesting its utility.

C then is the community specific constant which we must obtain. It is not clear what the absolute value will be for particular communities (I am currently attempting this), but some of the factors affecting C are of interest.

Generally C will vary depending on the taxon involved and the community type it occupies. The problem revolves around the inclusion of sufficient individuals of the species in question and their required symbionts to maintain populations above the critical breeding density. In some communities, individuals of species are sufficiently abundant that the per area redundancy of community components is high enough to maintain adequate populations without vast areal extent. The members of urban yard communities may be of this type, i.e., few species, generalists, small size, high densities, horizontal homogeneity. Thus, in a small area one may have a functioning example of a community type with all of its internal structure, e.g., energy flow (Falk 1976).

Communities composed of vagile, specialized, rare, sensitive, large-sized species and lots of them in a complex (heterogeneous) environment may require large areas to maintain their integrity.

Wilson and Willis (1975) refer to this in part under what they term truncation of ecological guilds, i.e., the early loss of specialists and large species on islands.

The obvious solution in a practical sense is to study and meet the needs of the species in the community of interest which has the greatest areal requirements. For communities as a whole, the island biogeography rule of thumb is that it takes a 10-fold increase in area to house twice as many species.

It is important to suggest here that species area curves and other types of calculations may also be appropriate. No one knows how far we may generalize from water-bounded islands to the community patch "islands" of terrestrial systems.

NUMBER OF REPLICATES — EXTINCTION

For each of the established reserves, one must remember that while its areal extent may be appropriate for the general maintenance of its component species, there is a tendency for species to become extinct. The implication of this fact is that replicate reserves of equal size must be used.

Terborgh (1974) uses the simple equation,

$$-\frac{dS}{dt} = kS^2;$$

where, $-\frac{dS}{dt}$ = rate of species loss; S = number of species, and k = coefficient of extinction, to estimate species loss.

The coefficient of extinction for various groups is derived empirically by the formula

$$k = \frac{\frac{1}{S_p} - \frac{1}{S_o}}{t};$$

where, S_p = number of species present at any time; S_o = initial number of species.

The absolute value of k depends, in part, on the pressures exerted by competing species; and thus varies from place to place. A nature reserve surrounded by a totally different community may be constantly bombarded with potential competitors and thus may have a high species replacement rate, while an isolated area with few infiltrating competitors loses species at a lower rate.

The consequences of these relationships has caused several workers to posit about the appropriate shape and numbers of nature reserves (Diamond 1975, Wilson and Willis 1975).

Figure 1 depicts several postulates derived from such thinking. Note that two simultaneous principles are involved in reasoning about these arrays. First, a circle has the highest area per perimeter ratio and thus should always be less susceptible to outside influences assuming such influences are related to perimeter extent. Second,

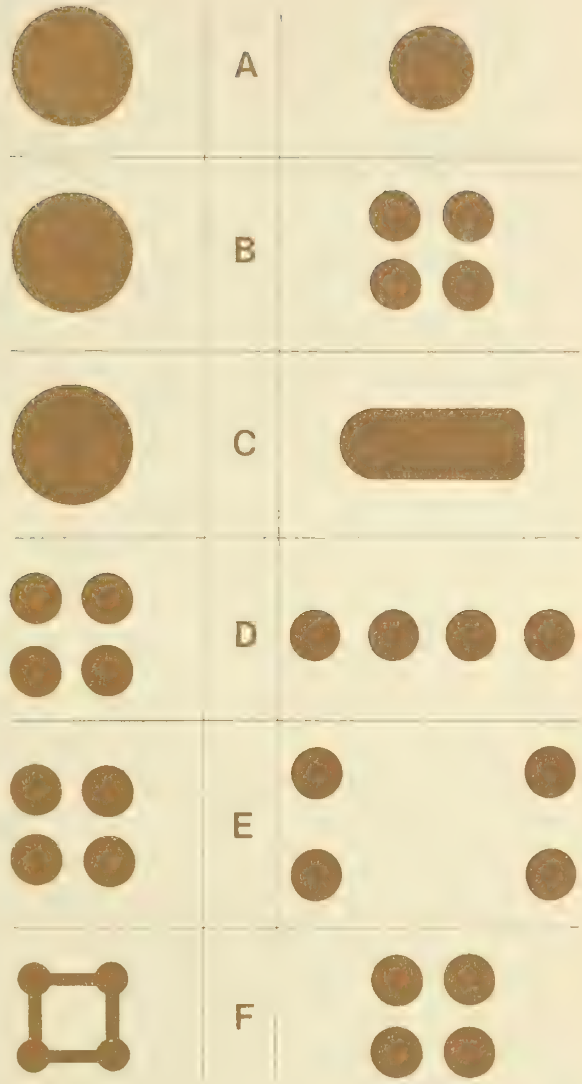

Figure 1.—Geometric relationships of reserves based on biogeographical principles (after Diamond 1975, Wilson and Willis 1975). Relationship in the left hand column is always more desirable than that in the right hand column. A. Larger reserve better than small, B. large reserve better than four small ones of equal total area, C. circular reserve better than any other shape, D. mutually adjacent areas better than linearly arranged, E. close replicate reserves better than distant ones, F. smaller but connected reserves better than separate but equal area reserves.

close, or better yet, connected (archipelago) replicates are superior because proximate similar areas act as replacement source areas for species to their homologues when extinction of species occurs. In addition, "invading species" are in reality the same species as the components of the invaded community.

PRACTICE

The approach to this point seems clear. First determine the minimum area necessary to maintain a community type. If in doubt, calculate the area for the most sensitive species (rare, large, highest trophic level, most vagile). Second, try to assess rate of extinction by determining the coefficient of extinction (k) for the most sensitive species. Then establish replicate natural areas making the practical trade-offs among size, number, and proximity. The ideal is a large number of large areas adjacent to and mutually interconnected.

The first consideration must be a sufficiently large minimum area. The second consideration would be to establish replicates, and the third, to establish these at proximate places.

The comments to this point imply that the higher the species density the higher the stability of the community and also that species number alone is the best indicator of required area.

These two assumptions need not be true. Stability of communities may result from several possibilities. The diversity-stability paradigm actually implies that species are interconnected and that stability results from this anastomosis. Communities of few species may consist of resilient members (broad ecological tolerances) and therefore resist the effects of perturbation. On the other hand, species-rich communities may have little biological coupling (coevolution) and therefore lack the stability of association.

Deserts seem to be composed of few highly resilient species. Rain forests may contain large numbers of species, but they are frequently specialized to the point of paralleling the precariousness of a parasite's mode of life.

Thus, to persist over the time axis a community must endure perturbation (resiliency) or have sufficient biological alternatives (redundancy) to fill roles as they are opened by extinction.

Despite the above counterintuitive relations of diversity and stability, deserts or rainforests (and all community types), wherever they are and whichever taxa comprise them, have startling similarities from mere physiognomy [e.g., Mediterranean scrub of Australia, Chile, California, etc., compared in Di Castri and Mooney (1973)] to interesting guild analogues (Pianka 1973; MacMahon 1976). This suggests that similar communities may be maintained with a similar management strategy regardless of their place of occurrence.

Since the best correlates for predicting community type are frequently abiotic factors, perhaps a starting point would be to determine optimum size and number from as few as the 30 "life zone" types (fig. 2) determined by Holdridge (1967). Holdridge's use of three environmental variables (annual precipitation, potential evapotranspiration, and mean annual biotemperature) to classify the entire earth is certainly a simple scheme--albeit somewhat too generalized.

The reduction of world variability to just thirty communities would allow us to use international cooperation to choose one example each of thirty types of vegetation, somewhere in the world, which would be examples of communities containing inherently unstable members. Scientists could then perturb such systems, derive "C" and from historical records perhaps estimate "k" and determine rational guidelines for conservation practices.

In the end, our ability to carry out this "ideal" plan will always be affected by "political" decisions. Nonetheless, in the long run we have no viable options other than to conserve examples

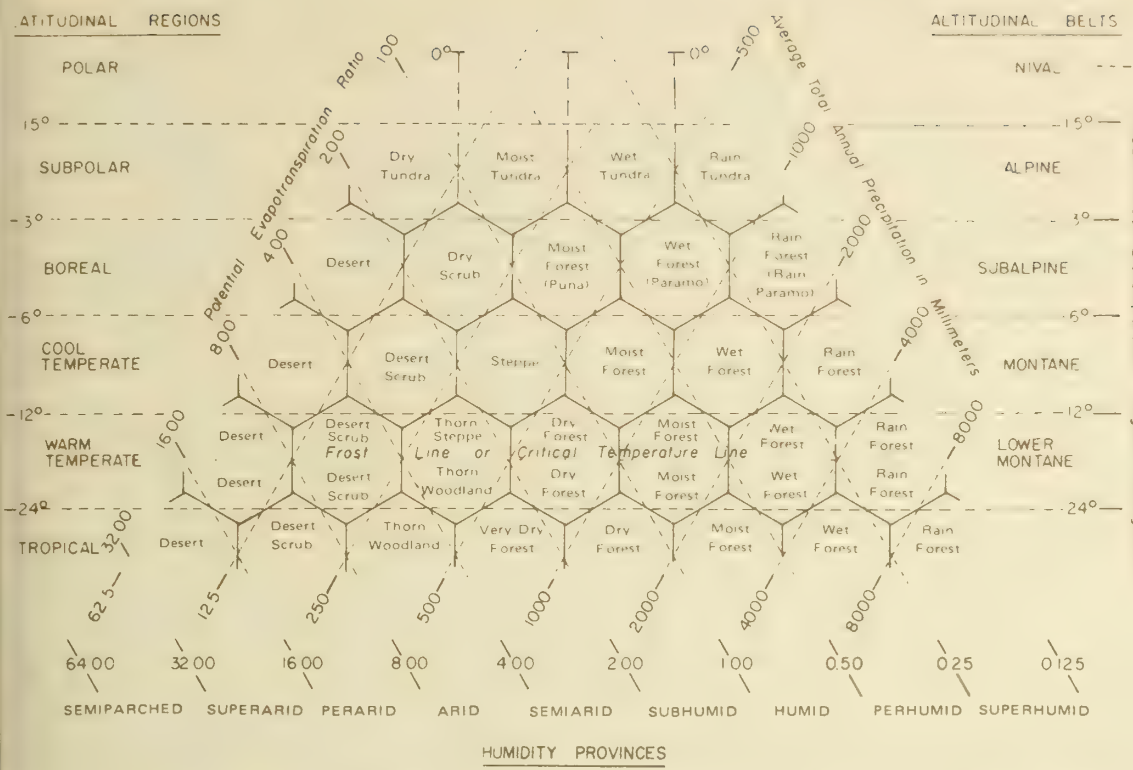

Figure 2.—Diagram for the classification of world life zones or plant formations (after Holdridge 1967).

of all species and ecosystems. Being a component of every world ecosystem, if man can not elucidate the systems' rules, his very existence is tenuous.

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An International View on BIOSPHERE RESERVES and Their Uses

Sequoia National Par

Thoughts on the Biosphere Reserve Concept and Its Implementation

by

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The popularity of (MAB) Project 8, "Conservation of natural areas and of the genetic material they contain," should not be a surprise. The topic is clearly one of universal appeal and importance. As natural ecosystems throughout the world are being altered on a massive scale, the importance of setting aside representative sites inclusive of the world's major ecosystem types can scarcely be questioned. The international network of Biosphere Reserves being developed within the framework of MAB Project 8 is intended to combine ecological preservation of representative ecosystems with research into the functioning of these ecosystems, investigations to analyze man's impact on natural systems, and development of the means to monitor this impact. Actually, Project 8 must constitute the backbone for the entire MAB program, by providing logistic support for such research. The provision of opportunities and facilities for education and training is an additional important function of Biosphere Reserves.

The Biosphere Reserve concept, first elaborated in MAB Report No. 22 (UNESCO 1974), has considerable flexibility and allows countries much freedom in adapting it to meet their specific needs. Although a variety of approaches are being taken, it appears to us that the concept is evolving to comprise the following major elements which distinguish it from complementary national conservation programs:

1. Emphasis on use of natural areas in research, including that which involves providing an improved scientific base for conservation;
2. Inclusion of man-modified ecosystems to serve as sites for comparative studies of natural and modified ecosystems;
3. Emphasis on conservation of ecosystems (with their full array of component species), rather than upon conservation of individual species;
4. Emphasis on providing sites for long-term continuity of research and monitoring;
5. Choice of sites for representativeness, rather than for uniqueness;

6. Provision for an international framework for cooperation among nations in conservation and research.

In summary, the establishment of an international network of Biosphere Reserves is a major endeavor in the field of conservation, unique in combining conservation, research, monitoring, and training and education elements and in linking protected areas in an international framework through the Man and the Biosphere (MAB) Program.

NATURAL AREAS AND RESEARCH

The need for a better scientific basis for biological conservation is consistently underestimated. It is true that conservation invariably involves many political, economic, and social considerations, but this is no justification for neglect of ecological theory in selection and management of sites. Inability of conservation area managers to provide for rational management often results in weakening of political support. A major cause of faulty management is lack of an adequate ecological information base. Improved ecological theory could contribute substantially to clearing political obstacles. Much more information is needed just to establish how much ecological preservation may be necessary or desirable. It is remarkable how poor the available information is. Advocates of ecosystem conservation are often badly handicapped by a very weak supply of the information necessary to convince governments of the need for conservation.

The esthetic, educational, scientific, cultural, and recreational values of natural ecosystems are generally well accepted but are understandably often regarded as luxuries both by developing and developed countries. The values of these areas as reservoirs of genetic material and for providing "public service" functions (term used by Biswas and Biswas 1976) are recognized only in a very general vague way because they are far from being fully understood. "Public service" functions include provision for control of potential agricultural pests, pollination of domestic plants, prevention of erosion, etc.

What percentage of the earth's surface and of individual ecosystem types must be maintained as relatively natural ecosystems in order to provide for global and regional stability of the biosphere? Given the present state of knowledge, ecologists are unable to provide an answer. What percentage of the earth's species (and which ones?) must be maintained to allow for this stability? Although no answers to these questions are possible, considerations from the theory of island biogeography (MacArthur and Wilson 1967) suggest that if 10 percent of a given ecosystem type is preserved, no more than 50 percent of the species dependent upon this type can be preserved in the long run (Slatyer 1975). If this assessment is correct, there is clearly immediate cause for much concern. The present small percentage of the earth's terrestrial surface devoted to National Parks and other ecological reserves appears to be inadequate for preservation of species which are dependent on natural ecosystems, and most areas

outside parks and reserves may be eventually subject to modification by man. These are critical questions which have high scientific priority, but are rarely asked.

We fully recognize that the present Biosphere Reserve network is not comprehensive enough to make a major direct contribution to preservation of the earth's genetic material and sustained operation of public service functions provided by natural ecosystems. Only through a concerted international effort toward a better understanding of functioning of natural ecosystems and man-modified ecosystems can answers to critical ecological questions be obtained. Among key topics for investigation is the relationship between the natural and man-modified systems: How does the latter depend on the former for productivity? This complex question must be approached from many different directions. Answers will not necessarily be similar for such diverse ecosystem types as tropical rain forest, savannah, and temperate deciduous forest. We hope that research carried out in Biosphere Reserves will aid in leading to a satisfactory answer to such questions.

MAN-MODIFIED SITES FOR USE IN COMPARATIVE STUDIES

A major research activity associated with Biosphere Reserves should be the comparison of natural and man-modified ecosystems, with the aim of providing information relevant to development of modified ecosystems which maintain long-term productivity for man's benefit. In order to assure availability of man-modified sites which are properly comparable to the natural ecosystems being preserved, Biosphere Reserves should include various types of modified sites.

A Biosphere Reserve will ideally consist of a core area, devoted to preservation of natural or near-natural ecosystems, surrounded by a buffer zone which should consist of ecosystems grading from natural and semi-natural adjacent to the core area, to strongly modified. The various types of modified sites should generally be included in the outer buffer zone.

Another logistical possibility is to have the modified sites geographically separate from the main portion of the Biosphere Reserve. A variation of this latter possibility being developed in the United States is the cluster concept of Biosphere Reserves, which involves a separation of the primary conservation site and experimental site for a given ecosystem within the Biosphere Reserve program.

CONSERVATION OF ECOSYSTEMS

The emphasis within the Biosphere Reserve program of ecosystem conservation rather than individual species conservation is by no means new or unique but is highly significant. Efforts at conservation of individual species are important and worthy of support, but must be aimed at relatively few species which are conspicuous

enough to attract attention and to stir human emotions. Programs aimed at individual endangered species will not be able to cope with problems such as those posed by modification of large areas of tropical forests. The total number of animal and plant species on earth is probably somewhere between the 1.5 million species which have been described and the 10 million postulated on the basis of extrapolation of species--abundance curves (Myers 1976). A large percentage of these species, both described and theoretical, are plants and insects of tropical forests, many of which are highly susceptible to habitat modification.

Efforts at saving individual species have the merit of dramatizing the problems of extinction, and research on a relatively few species can serve to elucidate the principles of the species extinction process. In the long run, however, efforts must be concentrated on preservation of an optimal extent of natural and semi-natural ecosystems. In spite of the need for expanding agricultural production and energy resource exploitation to support the world's growing population at a high enough level that their basic needs are satisfied, adequate land must also be set aside to allow for preservation of species and essential public service functions which, among other things, make agriculture possible. Fortunately, land which provides for stability of the biosphere can simultaneously function to satisfy esthetic, scientific, cultural, educational, and (under particularly careful management) recreational needs of mankind. Unfortunately, it appears inevitable that a substantial fraction of the earth's species is going to be lost unless a better rationale for saving them (through preserving their habitats) can be quickly formulated and drastic measures implemented immediately to counteract trends which are under way in tropical forests and elsewhere. A realistic strategy, which recognizes the minimum complement of species which must be maintained, must be developed on a scientific basis.

PROVISION OF SITES FOR LONG-TERM RESEARCH AND MONITORING

MAB Report No. 22 (UNESCO 1974) specifies that research within Biosphere Reserves should be at three levels: investigation of the structure, functioning and dynamics of a particular ecosystem; comparisons between ecosystems; and comparison in time. For the latter type of research, assured long-term site protection is, of course, essential. Important studies of this sort involve documentation of long-term trends including ecosystem recovery following disturbance by man, fluctuations related to periodic natural disturbance (as impact of natural fire), and effects of year to year climatic fluctuations or of long-term climatic change. Studies of this type have been traditionally neglected because of the difficulty of assuring site security.

Important follow-up studies have been done to classic studies of ecological pioneers when, often by chance, the study sites have been left intact. The need exists to remove the element of chance. Even in National Parks, research sites used in the past have not always proved immune to alteration for development. In Biosphere Reserves,

research must be recognized as a major use having priority over other uses which might jeopardize research sites.

When research sites remain intact, it is often possible to build on previous studies carried out at a single site to accumulate a comprehensive body of knowledge concerning the site even though large amounts of money for research may not be available at any one time. Progress in theory or technology may allow advances to be made over previous work at a site. Where very comprehensive studies have been carried out, there is much need for preserving the sites for follow-up studies. With this philosophy in mind, sites used in the International Biological program, such as Pasoh in Malaysia, Lamto in the Ivory Coast, H. J. Andrews Experimental Forest in the U.S.A., and Solling in the Federal Republic of Germany, have already or will probably become Biosphere Reserves.

CHOICE OF SITES FOR REPRESENTATIVENESS

The emphasis on representativeness rather than on uniqueness in the criteria for Biosphere Reserve choice is another very important consideration and a major distinguishing feature between Biosphere Reserves and the traditional concept of National Parks. Although Biosphere Reserve criteria given in MAB Report No. 22 allow for selection by countries of unique areas, the emphasis must be on sites representative of major ecosystem types. Unique areas are probably justified for Biosphere Reserve designation only when a considerable research effort is under way and when the area has much value in comparison with unique or typical areas of the general type in other parts of the world.

National Park systems have generally been developed with an emphasis on the unique, spectacular, and beautiful--not on protection of representative ecosystems. Since spectacular and beautiful landscapes often correspond with representative ecosystems, there are many cases where National Parks are well suited for incorporation into the Biosphere Reserve network.

There are two major reasons for the emphasis of MAB Project 8 on representative ecosystems:

1. to provide conservation and research sites covering as broad a range of the world's biotic diversity as possible; and

2. to allow extrapolation of research findings throughout a large area.

Representative sites may be difficult to find in some cases where whole ecosystem types have been almost completely converted to agriculture. This is the case for grassland ecosystems of North America and Europe. Some forest biomes have been so thoroughly modified that large samples of relatively natural forest are difficult to find--e.g., the Mediterranean forests and maquis. When near-natural ecosystems of these rare types can be found and protected, they have great value as "baseline" sites for gaining understanding of functioning of natural systems as background for understanding agricultural systems and degraded lands.

PROVISION OF AN INTERNATIONAL FRAMEWORK

The MAB program and Project 8 are concerned with problems which are shared by all countries; and success cannot be achieved without a high degree of international cooperation, including assistance from developed countries to developing countries and cooperation among countries which share similar ecological conditions. Indeed, the prime reason for initiating the program was to promote this sort of cooperation. The Biosphere Reserve concept has been well received by many countries. The generally accepted goal for MAB 8 of eventual establishment of at least one functioning Biosphere Reserve in each of the major ecosystem types of the world appears to be a realistic possibility within (UNESCO) member states which are participating in MAB. This world-wide network is to be linked by cooperation in the exchange of information and personnel (both scientists and managers).

Although provision of this international framework is an important aspect of MAB Project 8, the limits to its international nature should be clearly recognized. A country's sovereignty is in no way affected by creation of a Biosphere Reserve within its territory. Each individual country participating in the program has the responsibility to provide protection for its own Biosphere Reserves by establishing and enforcing an adequate legal framework. Regulation of access and use of a Biosphere Reserve rests entirely with the country which establishes it. Scientists wishing to carry out ecological research within a Biosphere Reserve can do so only with permission of the appropriate authorities of the host country.

THEORETICAL FRAMEWORK FOR THE NETWORK OF BIOSPHERE RESERVES

As stated above a major goal of MAB 8 is eventual establishment of at least one functioning Biosphere Reserve in each of the major ecosystem types of the world. These sites are to be selected taking into consideration the following criteria (UNESCO 1974): 1. representativeness, 2. diversity, 3. naturalness, and 4. effectiveness as a conservation unit.

The criteria (UNESCO 1974) also allow for selection of "unique" areas and of "man-modified" areas, including "varied and harmonious landscapes" and "modified or degraded landscapes." The contribution of such sites to the MAB 8 program as a whole will depend largely on their value in research and on their comparability with representative natural sites of the network. Because of their specialized nature, they will not be considered further in this paper.

As a framework for the network of Biosphere Reserves, IUCN has recently produced, under contract with UNESCO, a publication by M.D.F. Udvardy (1975), which divides the world into 193 biogeographical provinces, based on physiognomy of vegetation and on floristic and faunistic differences between regions. Ray (1975) has produced a similar classification for coastal and marine ecosystems of the world. Although Udvardy's classification has many merits, a classification at this scale must be rather artificial and arbitrary so

that a reader with moderate knowledge of biogeography readily finds many details to criticize. Udvardy has, however, succeeded in providing an adequate theoretical framework for the network of Biosphere Reserves. Each of the 193 biogeographical provinces falls in one of 14 "biome types" and in one of 8 "terrestrial biogeographical realms," forming a biogeographical-ecological matrix as shown in table 1. When Biosphere Reserves have been established in most biogeographical provinces, the opportunity will exist for comparative studies between areas of the same "biome type" but in different "biogeographical realms."

Thus, Udvardy recognizes 18 major types of "tropical humid forest" --7 in South and Central America, 3 in Africa (including part of Malagasy Republic), 7 in the Indo-Malayan region, and 1 in Australia. Ideally, at least one Biosphere Reserve should represent each of these 18 biogeographical provinces. Each of these Biosphere Reserves would differ greatly from the others in fauna and flora, but all would share many characteristics common to all tropical humid forest. Management principles worked out in one of these areas would have potential for application in the other areas.

Most of Udvardy's 14 biome types can be further subdivided to provide better resolution in selecting areas for comparative studies. Some prime types for comparative ecological studies include regions with temperate rain forest (which share problems of maintenance of high quality watersheds subject to forest exploitation); regions with "mediterranean-type" sclerophyll vegetation (which share problems of fire management); and various islands with similar climate (which share problems of invasion by exotic species).

PRACTICAL ASPECTS INVOLVED IN IMPLEMENTATION OF MAB PROJECT 8

The fourth session of MAB's International Co-ordinating Council established a procedure according to which countries can propose areas for formal designation as Biosphere Reserves, through submission of information on the proposed areas in accordance with a standard format. Authority was delegated to the Bureau of the International Co-ordinating Council to approve or disapprove applications.1/

Experience during two years since a MAB Expert Panel established criteria and guidelines for biosphere reserve establishment (UNESCO 1974) shows that pragmatism is necessary in implementing MAB Project 8. For example, in selecting areas for designation as Biosphere Reserves, some countries have emphasized the conservation aspect of MAB 8, while others have emphasized the research aspect.

1/ At the meeting of the Bureau of the International Co-ordinating Council of MAB held in June, 1976, the first Biosphere Reserves--57 in number from 9 countries--were formally approved and will receive a certificate of formal recognition from UNESCO. Over 150 additional areas have been provisionally identified by countries for intended designation as Biosphere Reserves.

Table 1--Biogeographical-ecological matrix, showing numbers of "biographical provinces" for each of Udvardy's 14 biome types which occur within each 'terrestrial biogeographical realm.' (Based on Udvardy, 1975)

Biome types	Terrestrial biogeographical realm								
	Nearctic	Palearctic	Africo-tropical	Indo-Malayan	Oceanian	Australian	Antarctic	Neotropical	Total
Tropical humid forests	--	--	3	7	--	1	--	7	18
Subtropical and temperate rain forests or woodlands	2	2	--	--	--	1	1	4	10
Temperate needle-leaf forests or woodlands	2	2	--	--	--	--	--	--	4
Tropical dry or deciduous forests (including monsoon forests) or woodlands	--	--	7	[illegible]	--	1	--	10	25
Temperate broad-leaf forests or woodlands and subpolar deciduous thickets	2	10	--	--	--	--	--	1	13
Evergreen sclerophyllous forests, scrubs, or woodlands	1	2	1	--	--	4	--	1	9
Warm deserts and semi-deserts	3	3	6	1	--	3	--	2	18
Cold-winter (continental) deserts and semi-deserts	1	4	--	--	--	--	--	1	6
Tundra communities and barren arctic desert	6	3	--	--	--	--	3	--	12
Tropical grasslands and savannas	--	--	--	--	--	2	--	4	6
Temperate grasslands	1	4	--	--	--	1	--	2	8
Mixed mountain and highland systems with complex zonation	3	9	5	--	--	--	--	5	22
Mixed island systems	--	2	3	12	7	--	--	9	33
Lake systems	1	3	4	--	--	--	--	1	9
Total	22	44	29	27	7	13	4	47	193

The largest and best potential sites for conservation purposes are often remote from scientific institutions, and there is a tendency to concentrate research efforts in relatively accessible areas. In some countries, the major representative ecosystem types have been largely converted to agriculture or degraded, so that the remnants available for preservation are not large and may not have intact complements of fauna and flora. Consequently, some large Biosphere Reserves are being established where research may not be carried out immediately. Some small Biosphere Reserves are being established where intensive research is under way. The majority of sites lie between these extremes.

The ideal situation would be to have large, well-protected Biosphere Reserves with comprehensive research projects in all biogeographical provinces. This is a worthy goal to work toward, but must not be followed over-zealously at this stage in the program. Emphasis must be upon getting functioning Biosphere Reserves established where countries have the willingness to establish them. Sites which clearly fail to meet the test of "viability as a conservation unit" (MAB Report No. 22 - UNESCO 1974) cannot be accepted as part of the world-wide network. "Viability as a conservation unit" is, however, a relative concept. Even some of the world's largest conservation areas fail to contain complete habitats for wide-ranging migratory mammals, while very small areas can serve as useful conservation sites for some sedentary species. Standards must be applied most leniently in ecosystem types where habitat modifications has been most widespread.

As far as the role of UNESCO and the MAB Secretariat in further stimulating the development of MAB Project 8 is concerned, the immediate priorities appear to be as follows:

1. Encourage countries to develop their own network to the fullest possible extent in accordance with Biosphere Reserve criteria to the fullest extent possible.

2. Encourage cooperative links between countries with Biosphere Reserves representing similar ecosystem types--including exchange of information and personnel.

3. Continue to work to ensure full-fledged support of international organizations, such as IUCN, (UNEP), and (FAO) for MAB Project 8. Development of the Biosphere Reserve network is one of the concerns of the "Ecosystem Conservation Group," formed in 1975, which is attended by representatives from UNESCO, IUCN, FAO, and UNEP and is chaired by UNEP.

4. With funds available, provide for assistance to developing countries to develop potential Biosphere Reserves into functioning Biosphere Reserves. A current project under way in Southeast Asia is giving initial experience in this type of activity. It will be necessary to actively seek funds from all possible sources to make MAB Project 8 a success in developing countries. Plans are under way to prepare proposals for cooperative efforts with IUCN.

In large measure, however, the successful evolution of the Biosphere Reserve network is dependent on the initiatives of individual countries participating in MAB. The initiatives taken by the U.S.A. and U.S.S.R. in development of MAB Project 8 and reported at the bilateral symposium have resulted in many new ideas and are welcomed enthusiastically by UNESCO.

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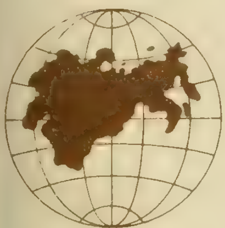
Soviet Views on

BIOSPHERE RESERVES and Their Uses

The Biotic Diversity of the Northern Hemisphere — Problems of Study and Conservation



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Rational conservation of the flora and fauna should be preceded by regionalization of the water or land surface, i.e., the establishment of an hierarchic system of regions encompassing the entire land surface including internal bodies of water or the entire area covered by seas and oceans. This type of regionalization can only be carried out on a typological basis, i.e., every region differs from others by the range of plant associations and by fauna and flora; in other words, by types of biomes and biotas.

The problem of regionalization is also aggravated by the fact that the geographic distribution of biotas and biomes is determined by several groups of factors.[1] Some of them are zonal in nature, others are non-zonal. The interplay of these factors creates the diversity of life conditions. Therefore, every region, regardless of its rank, is characterized by the combination of three types of associations: zonal ones which occupy elevated, well-drained upland soils of medium mechanical compositon; associations of intra-zonal character which do not occupy zonal environments but occur in several (or the majority) of the world's zones (e.g. marshes, solonchaks, solonetz, etc.); and extra-zonal or azonal associations which are zonal in a neighboring zone but are confined to an extra-zonal environment in the given zone (for instance, steppes on the southern slopes among forests: oak forests in steppe ravines, etc.). This pattern is complicated by the vertical zonation which differs in different mountainous countries as the result of their geographical position as well as aspect and steepness of slopes, extent of talus and rock exposure, etc.

It may be added that the structural and functional peculiarities of communities are primarily determined by modern ecological conditions while their flora and fauna depend equally upon more recent geological history. Owing to this, the factors which determine peculiarities of the biota, on the one hand, and the properties of the biomes, on the other, are dissimilar. This has provided the basis for suggestions that it is fundamentally impractical to develop a master system of regional categories for both the biota and biomes.

[1] Biome is an aggregate of vegetation and animal populations. Biota is an aggregate of flora and fauna.

As indicated by A. F. Emelyanov (1974) there are, however, general regularities in the distribution of plants and animals (and, we may add, their associations). This phenomenon is determined by: (a) the fact that the same abiotic factors (the climate primarily) affect both plants and animals; and (b) biogeocenotic relationships in the distribution of plants and animals, which developed in the process of their coexistence and in the course of the biotic transformation of life conditions.

Thus, we consider (following A. F. Emelyanov) that the prevailing factors of organism distribution have many similarities. This allows the possibility (and the necessity) of developing a master general geographical scheme of regionalization. This certainly does not exclude the use of available data on the distribution of various groups to create particular charts of biogeographic regionalization. The charts based on some groups (angiosperms, for instance) may be applied in the analysis of the spread of other groups (insects, for instance). Regionalization based on relatively small taxonomic groups should be viewed, according to A. F. Emelyanov, as the material for building and improving general biogeographical regionalization charts.

We believe that it is possible to trace only large-scale delimitations on the distribution of vertebrates. Most of the representatives of this group have inter-landscape activity and only relatively few intra-landscape activity. Practically all invertebrates are confined to the smallest-sized natural, territorial complexes. The immobility of plants makes it possible to use them for regionalization at any level.

Thus, the joint regionalization of a biota and biomes is possible and necessary. The most recent efforts of compiling this type of combined regionalization were made by R. Dasmann (1974) and M. Udvardy (1975).

We believe that the regionalization system suggested by these authors may be taken as the initial document for compiling a coordinated international program of environmental protection measures. Our remarks refer to the dismemberment of only one biogeographic region - the Palearctic, most of which is within the U.S.S.R. and neighboring countries. R. Dasmann and M. Udvardy are not fully acquainted with data and concepts of Soviet specialists. This explains a number of inaccuracies in their draft subdivision of Palearctic into biogeographical provinces.

The idea of our chart is to preserve, as far as possible, the names and the boundaries of provinces singled out by R. Dasmann and M. Udvardy and to make alterations only where facts contradict the concepts of the mentioned authors. Similarly, we have preserved the order of coding the provinces suggested by M. Udvardy (I.I.I.): Biogeographical region (realm) - biogeographical province - the type of biome (table 1, fig. 1).

Table 1--Biogeographical Provinces of the Palearctic

Code	Name of biome	Type of biome
2.1.1.	North Eurasian	tundra
2.2.2.	Icelandic	meadow
2.3.2.	Kamchatkan	meadow
2.4.3.	West Eurasian	taiga
2.5.3.	East Siberian	taiga
2.6.3.	Okhotsk	taiga
2.7.3.	South-Siberian	mountain-taiga
2.8.4.	British	broadleaved
2.9.4.	Atlantic	broadleaved
2.10.4.	Central European	broadleaved
2.11.4.	North European	coniferous-broadleaved
2.12.4.	Iberian	mountain-broadleaved
2.13.4.	Central European	mountain-broadleaved
2.14.4.	Balkan	mountain-broadleaved
2.15.4.	Black Sea-Caucasian-Girkan	mountain-broadleaved
2.16.4.	Amur-Manchurian	coniferous-broadleaved
2.17.4.	Central Chinese	broadleaved
2.18.5.	Mediterranean	evergreen hardleaved forests
2.19.5.	Atlass	evergreen hardleaved forests
2.20.5.	Zagross	evergreen hardleaved forests
2.21.5.	Himalayan-South Chinese	evergreen hardleaved forests
2.22.5.	Nan-shan-ling	evergreen hardleaved forests
2.23.5.	Japanese-South Korean	evergreen hardleaved forests
2.24.6.	Pannonian	steppe
2.25.6.	Anatolian	steppe
2.26.6.	East European	steppe
2.27.6.	Kazakhstan	steppe
2.28.6.	Mongolian	steppe
2.29.6.	East Khingan	steppe
2.30.7	Saharan	desert
2.31.7.	Arabian	desert
2.32.7.	Mesopotamian-Sindian	desert
2.33.7.	Uranian	desert
2.34.7.	Turanian	desert
2.35.7.	Caspian-Bet-pak-dala	desert
2.36.7.	Gobi	desert
2.37.8.	Central Asian	high mountain
2.38.8.	Tibet	high mountain
2.39.8.	Kam	high mountain
2.40.9.	Caspian	lake
2.41.9.	Aral	lake
2.42.9.	Baikal	lake
2.43.9.	Ubsu-Hur	lake

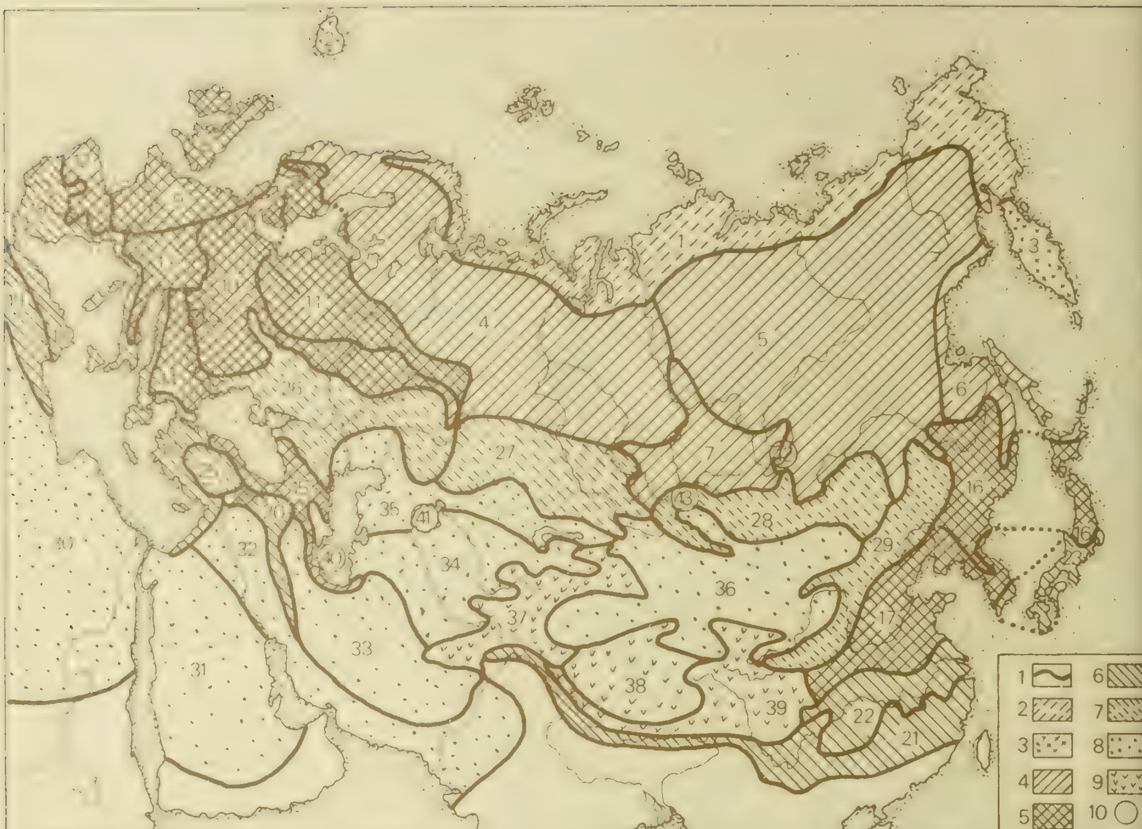

Figure 1.—Biogeographical Regions of the Palearctic: (1) region boundaries; (2) tundra biome; (3) ocean meadow biome; (4) taiga biome; (5) broad-leaf forest biome, green in summer; (6) evergreen, hard-leaf biome; (7) steppe biome; (8) desert biome; (9) alpine biome; (10) lake biome. Names of regions (Provinces) correspond to the numbers on the figure; vide, table 1.

For the Palearctic, M. Udvardy singles out 44 biogeographical provinces which relate to the following 11 types of biomes[2/]: (2) subtropical and temperate rain forests; (3) temperate coniferous forests; (5) broadleaved temperate forests and subpolar deciduous thickets; (6) evergreen sclerophyllic forests and shrubs; (7) hot deserts and semi-deserts; (8) deserts and semi-deserts with a cold winter (continental); (9) tundras and arctic deserts; (11) temperate grasslands; (12) mixed ecosystems of mountains and highlands with a range of altitudinal belts; (13) mixed insular ecosystems; (14) lake ecosystems.

In our chart, the Palearctic is divided into 43 provinces which belong to nine types of biomes. The distinction from M. Udvardy's chart is in a somewhat different interpretation of the types of biomes and classification of specific provinces with these types

2/ The name of the type of biome is preceded by its code number.

(table 2). Five types of biomes are practically identical. In our and M. Udvardy's maps (our No. 1 is No. 9 in M. Udvardy's; No. 3 - No. 3; No. 4 - No. 5; No. 6 - No. 11; No. 9 - No. 14), and in a number of other cases the difference is merely in names which we tried to render more laconic.

Table 2--Types of biomes and number of their biogeographical provinces in the Palearctic

Number	Type of biome	No. of provinces	Province
1	Tundra	1	1
2	Ocean coastal meadow	2	2-3
3	Taiga	4	4-7
4	Deciduous broad-leaved forest	10	8-17
5	Evergreen hard-leaved forest	6	18-23
6	Steppe	6	24-29
7	Desert	7	30-36
8	Highlands	3	37-39
9	Lakes	4	40-43

We agree with E. M. Lavrenko (1950) that it is expedient to single out the ocean coastal meadow biome (No. 2). It is also necessary to single out the vast highland biome which should include the high mountains of Middle and Central Asia, Tibet, Kam and, possibly, the alpine belt of some other mountains. The flora and fauna, vegetation cover and the animal life, of this type of a biome has, by both its present day composition and history, very little in common with the desert biomes although most authors place it with Central Asian highlands. At the same time, there are no grounds, at least in Africa and Asia, for breaking the desert biome into two types (warm deserts and cold ones). In our view, placing Iranian deserts in the polar deserts and tundra biome (2.24.9.; 2.25.9.; and 2.26.9.) and forest-tundra with Atlass, Pontian and Mongolo-Manchurian steppes (2.27.11.; 2.28.11.; 2.29.11; 2.30.11.), as suggested by M. Udvardy, is also invalid. It is hardly expedient to pool a large group of mountain provinces (there are nine of them in M. Udvardy's chart, which differ radically in vertical zonality) into one type of a biome: "mixed mountain systems with complex zonality". Smaller distinctions between our suggestions and the views of M. Udvardy are apparent in table 1 and figure 1.

It should be noted that the Dasmann-Udvardy classification does not take into consideration one essential factor: the increase in floristic-faunistic differences from poles to the equator. Thus, many species have circumpolar ranges in the "tundra and polar desert" biome in contrast, the humid tropical forest biome presents such sharp floristic and faunistic distinctions that, in many cases, families and even orders prove to be endemic for different provinces

of a biome of one and the same type. Considering this, we are listing the Palearctic biomes from north to south while the provinces belonging to one and the same type of a biome - from west to east.

We have undertaken an effort to describe the extent of anthropogenic transformation of biogeographical provinces of the Palearctic (table 3, fig. 2).

Table 3--Anthropogenic transformation of palearctic biogeographical provinces (regions)

Degree of anthropogenic transformation	Number of region	
	Considerable portions affected	Affected in spots
Practically not affected	1, 30, 31, 36, 37, 38 39	6, 7
Affected:		
Weakly	3, 5, 6, 7, 28, 34, 35	1, 32
Moderately	4, 15, 16, 29, 33	3, 5, 13, 27, 30 31, 37, 39
Greatly	2, 11, 12, 14, 19, 20, 21, 22, 25	4, 16, 35
Transformed:	8, 9, 10, 13, 17, 18 23, 24, 26, 27, 32	14, 15, 21, 22, 29, 33, 34

The completely and strongly transformed provinces include 8 out of 10 provinces of the biome of deciduous broadleaved forests (Nos. 8-11 and No. 17), all 6 provinces of the biome of hard-leaved evergreen forests (Nos. 18-23), and 4 of the steppe biome provinces (Nos. 24-27). Practically no primary biocenosis survived on the territory of these provinces over any or most of their area. The prevailing landscapes (ploughland, industrial objects, communities, etc.) are of anthropogenic character having no natural analogues. The so-called "natural biocenoses": forest tracts and patches of unforested "virgin land" (marshes, meadows, steppes), are usually situated in areas which are unfit for economic use and have completely lost their original appearance. In these cases, only an attempt can be made on small reference territories to restore semblance of the original, once-dominant communities - sort of "nature museums". The sooner this effort is undertaken the greater the chance of its success.

The practically untransformed or weakly transformed provinces include one in the tundra biome (No. 1), one of two provinces in the ocean coastal meadow biome (No. 3), three out of four provinces in the taiga biome (Nos. 5-7), one out of six in the steppe biome (No.

Figure 2.—Degree of anthropogenic transformation of biogeographical provinces (regions) of the Palearctic: 1-5 considerable portion of the territory affected, 6-10 affected in spots. 1 and 6 are practically not affected, 2 and 4 are weakly affected, 3 and 8 are moderately affected, 4 and 9 are greatly affected, and 5 and 10 are transformed.

five out of seven in the desert biome (Nos. 30-31 and 34-36) and all three provinces of the highland biome (Nos. 37-39). The present tasks of nature conservation within these provinces seem quite simple delimitation of typical and sufficiently large reserve territories. It should be taken into consideration that until recently it was precisely these biomes that were deemed unsuitable or poorly suited for permanent human habitation, while they are presently being intensively developed for economic reasons. The ecosystems of these biomes are easily destroyed. Their original aspect can be restored with great difficulty and only very slowly.

Only five provinces of the Palearctic, belonging to four types of biomes, can be classed as moderately transformed (table 3). The provinces include a considerable number of sections which are weakly damaged by man's activity.

It is necessary to mention some general principles of nature conservation. Until recently, attention was centered on the protection of unique objects of nature occupying small-size territories

(relict communities, caves, picturesque areas, etc.). Today there is a general preoccupation with the necessity of conserving more typical, prevailing, and recently widespread communities which have continued from the first to undergo anthropogenic transformation. Surprising as it may seem, some of these once-dominant associations of biomes of the evergreen hardleaved forests, steppes, and deciduous forest have not survived, and the possiblity of recreating them is highly doubtful. It is absolutely necessary to attract public attention to the need of conserving these natural associations which served as the cradle of civilization.

Every biome and the biogeographical provinces on its territory are characterized by a combination of communities and not just the prevailing ones. To use the term of V. B. Sochava (1975), we are dealing not with biocenochores but with biocenomeres, i.e., not with categories of different ranks encompassing typological units of different level but with categories including combinations of territorially-conjugated associations ("facias"3/, "urochischas"3/, "localities"3/ and landscapes) of increasing area and complexity.

It is important from the conservation viewpoint to recognize that any province incorporates (as it was mentioned earlier) zonal, intra-zonal and extra-zonal associations and some species of plants and animals which are confined to only one of the groups or conditions. Therefore, a protected territory should be delimited so as to encompass a variety of types of communities confined to differing morphological parts of the landscape, differing elements of topography, soils of various mechanical and chemical composition, etc.

In addition, different approaches should be used to protect communities and to protect plant and animal species. These distinctions are based on the following:

The protection of biocenosis is a much more difficult task than the protection of individual species since a species cannot be destroyed without destroying (directly or by changing the environment) the prevailing part of its representatives. Furthermore, species can be preserved at botanical and zoological gardens or in the reserves where they are specifically protected. On the other hand, even a moderate human action upon a biocenosis (mowing, grazing of domestic animals, destruction of the moss cover in forests, etc.), or an excessive increase in the number of some herbivorous wild animals, like that of the moose in some parts of the forest zone of the U.S.S.R. might lead to the replacement of an association. It is true that natural communities have the ability of self-restoration but this ability is not infinite. As soon as a community passes its tolerance limit, changes become irreversible and different lasting derivatives or artifical communities develop on the territory.

Complete conservation of all protected objects even on small territories with numerous centers of endemism involves either the establishment of a huge number of small reserves or carrying out nature conservation measures on areas of such vastness excluding them from economic use that it becomes impracticable.

3/ Russian terms having no English versions.

Therefore, the biota and biomes can be protected only by applying a variety of measures. Besides the establishment of exclusive reserves including biosphere reserves or national parks (with controlled access for tourists and vacationers), there should be protected territories of other types: fixed-term preserves, individually protected nature monuments, etc. Maintenance of certain species in artificial conditions--zoos, botanical gardens, etc.--is also necessary. Certain objects should also be protected on territories which are used by man and which, under any circumstances, will comprise the greater part of land surface.

A first approximation of the availability of reserves in biogeographical provinces of the Palearctic, is seen on table 4 (fig. 3). It is noteworthy that there are no reserves in the practically untransformed or weakly transformed provinces (table 3). For instance, there are no reserves in the sole province of the tundra biome, two provinces (Nos. 5 and 6) of the taiga biome. one province (No. 28) of the steppe biome, five provinces (Nos. 30-33 and 35) of the desert biome, and two provinces (Nos. 38 and 39) of the highland biome. Similarly, there are no protected territories in the provinces of the oldest farm crops (Nos. 17, and 20-22). As for the first group of provinces, the possiblity of establishing reserves is not altogether lost and they should be established there in the next decade. Particular attention is drawn to the Mongolian province (No. 28)--it is the only province of the steppe biome of the Palearctic which is preserved in the natural state. The establishment of a reserve on its territory is an urgent matter. As for the provinces of the oldest agricultural crops, the very possibility of establishing reserves of adequate size and, specifically, of restoring the peculiar primary conditions of these biocenoses are highly doubtful.

The information offered will doubtless be amended and supplemented; we believe, however, that it generally agrees with reality. It will be interesting to ascertain the extent of man-caused damage and the rate of availability of reserves in the Nearctic biomes and biotic provinces which are similar to the corresponding biomes and biotic provinces of the Palearctic.

Table 4.--Territories of the biogeographical Palearctic regions provided with Zapovedniks

Presence of Zapovedniks	No. of biogeographical region
None	1, 5, 6, 7, 17, 20.[2], 21, 22, 28, 29, 29, 30, 31, 32, 33.[2], 35, 38, 39
Present:	
Few	3, 24, 25, 27, 34, 36
Sufficient	2, 4, 7, 8, 9*, 10, 11, 12, 13, 14, 15*, 16, 18*, 19, 23, 26, 37

* M spots

Figure 3.—Biogeographical Regions of the Palearctic provided with Zapovedniks: (1) boundaries of regions, (2) none, (3) few, (4) sufficient, (5) sufficient in certain spots.

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The Influence of Pollution on the Biosphere and Its Monitoring Based on Biosphere Reserves

by

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The increasing intensity of anthropogenic influences upon the environment urges the establishment of such priority tasks as the development of an optimal system for observation and appraisal of biosphere conditions and trends, as well as the elaboration of measures based on the data supplied by that system for effective regulation of the quality of the environment and for reducing harmful anthropogenic influence on the biosphere. Hence, the theory of retrieving and processing information on the state of the biosphere, pollution levels, and the reaction of the biota (individuals, populations, and ecosystems) to environmental factors becomes important.

To design an optimal program of regulating the quality of environment it is imperative to have precise answers to the following questions:

1. What is the background environmental condition?

2. What is the observed state and the observed level of anthropogenic influence on the biota?

3. What is the critical level of anthropogenic influence on the biota?

4. What is the permissible level of anthropogenic influence on the biota?

The answer to the first, and largely to the second question should be provided by a subsystem of national, and partially global monitoring of biosphere reserves.

Biosphere reserves should be the most essential component of the entire system of observation, evaluation, and forecasting of the state of the environment; since, we believe that in the identification of permissible levels of anthropogenic influence on the biosphere, it is necessary to use as a reference base the parts of the biosphere free from local influences. It is necessary to take into consideration all environmental components, e.g., an individual organism, a population, an association, an ecological system, and, finally, the biosphere as a whole.

To determine the maximum permissible burden, it is essential to formulate what quality of environment we consider as high (adequate). We believe that for a definite ecosystem, the high quality of environment should incorporate: (a) the possibility of stable existence and development of the given and historically man-made or transformed ecological system in a given place (district); and (b) the historical or temporary absence of unfavorable consequences for any population (first and foremost being human) in a given place. In this case, we may speak about the quality of environment for the given population.

There are identifiable biological (ecological) criteria which characterize a high quality of environment: high biological productivity, optimal species composition and ratio, the biomass of populations at different trophic levels, etc.

In the broadest sense, we may interpret as the permissible anthropogenic load (which is produced by individual homogeneous and heterogeneous influences) which does not alter the quality of environment or which alters it within permissible limits, i.e., does not induce destruction of existing ecological systems nor the emergence of unfavorable consequences in the most important populations (first and foremost being human populations).

Let us introduce a certain function of the state of the ecosystem or of another element of the biosphere (characterizing, for instance, the biomass volume, productivity, the rate of metabolism and energy in a system, or the combination of these and other similar factors). In $\zeta(\bar{R},t)$ (changes in space and time), or the generalized function for the region, we have

$$\zeta^*(t) = \int_{\bar{R}} \zeta(\bar{R},t)\, d\bar{R} \tag{1}$$

This function can represent the entire ecosystem or for any level or any population, and then be considered with the limits permissible for it.

Let us introduce the function of anthropogenic influence capable of altering the state of the given ecosystem $H(\bar{R},t)$ or

$$\varkappa^*(t) = \int_{\bar{R}} \varkappa(\bar{R},t)\, d\bar{R} \,. \tag{2}$$

Then, the function

$$\mathcal{Z}_a^*(t) = \mathcal{Z}^*(t)\,\varkappa^*(t)$$

describes the altered state of the biosphere elements under the influence of the given anthropogenic factor.

To establish a monitoring system, it is necessary to select the site of a station in a way that satisfies the following conditions:

$$\frac{\int_{\bar{R}} \mathcal{Z}_n(\bar{R},t)\,d\bar{R}}{\int_{\bar{R}} \mathcal{Z}_n^{u_{3}m}(\bar{R},t)\,d\bar{R}} \geq 0.7 - 0.8$$

where $\mathcal{Z}_n^{u_{3}m}$ is the function of the condition obtained by measuring with the help of the given system. Condition (4) is therefore a criterion for selecting and organizing a sufficient system of monitoring (e.g., a network of stations). In some cases, a considerable number of stations shall be established, in others even a small number will produce highly representative data. For instance, to arrange a monitoring system of influence upon a human population a large number of stations will be needed in towns and industrial districts (where the intensities of factors of influence are high), and a smaller number of stations in rural districts.

A smaller number of stations will be required to observe the state of vegetation, since only a small share of it grows in towns, whereas the bulk grows in zones of intermediate (regional level) or weak (background level) influence. It will be necessary to have specialized observations made in farming zones where vegetation is subjected to pesticide influence. A specific network will be also required to observe the pollution of the ocean and its impact on the biota.

A very small number of stations can give sufficient information on the state of the flora and fauna in the conservation areas for animal and plant genetic pools (reserves). The creation of a comparatively small number of biosphere reserves (stations) capable of a wide range of measurements and studies will be of a considerable value in their own right.

Thus, a combined theoretical and operative program of activity at biosphere reserves should be decisive in designing an optimal strategy for man in the way he relates to his environment.

Another important task of biosphere reserves, along with the evaluation of biosphere conditions and their tendency to change, is the study of the function and structure of ecosystems, in order to work out scientifically valid indicators of the state of ecosystems. Indeed, precisely this set of studies (known as biological monitoring) is the least theoretically developed and, therefore, the least applicable in practice. At the same time, one must develop an optimal strategy of controlling the quality of the natural environment and, in particular, an optimal system of evaluation and forecasting the state of the biosphere. During a time of rapid technical progress, one has to know not merely the influence of pollutants and other factors on man's health but also on other organisms and ecological systems. One must know not merely the effect of one or another pollutant but the effect of the entire range of chemical, physical, and biological factors which influence the biosphere and all its elements concurrently. One must understand not only the influence of environmental factors upon the structure and functioning of ecosystems but the dynamics of these indicators as related to the dynamics of the changing chemical and physical indices of the state of environment (for instance, global or local climatic changes).

Baseline observations are in their infancy. Their main goal is information on the initial state of the biosphere, its present level of pollution, the ways and rate of spread of pollutants over great distances, and directions in the changes of environmental quality. Observations should also make it possible to distinguish the unfavorable changes caused by human activity against a background of natural processes. The resulting information is necessary to understand the basic physicial, chemical, and biological processes; to broaden our knowledge of the influences upon ecological systems and the biosphere as a whole; and to determine, in the final analysis, the present directions of environmental changes, to work out forecasts for the biosphere and recommendations for the optimal control of environments, including the global environment.

The aim of baseline observations may be fully achieved only if this work is conducted on a global scale. Thus, any national system of baseline observation is a component of a global system. In this respect the network of baseline observation which is being developed in the U.S.S.R. provides for concurrent participation in a number of large international projects, like the Global Environmental Monitoring System (regional and base stations), United Nations Environmental Program (monitoring of atmospheric pollution by the World Meteorological Organization), 8 and 14 projects of the United Nations Educational, Scientific and Cultural Organization, "Man and Biosphere" program, biosphere reserves, etc. At the present time, the main concepts of background monitoring have been developed and are included in appropriate international documents drafted by the above-mentioned international organizations.

It is intended to establish in the U.S.S.R., for baseline monitoring, a series of terrestrial biosphere reserves and at least one marine biosphere reserve in the central Atlantic. When selecting the sites for the biosphere reserves, the extent of

anthropogenic influence in a given area and the representative character of the physiographical zones will be taken into consideration. At least one biosphere reserve will be situated in tundra, desert, taiga, and forest-steppe zones. This is where the maximum program for background monitoring will be implemented and will include ecological and biological studies.

The program of baseline monitoring provides for the following observations: in atmospheric air, sulphur dioxide, carbon monoxide and dioxide, nitric oxides, ozone, reaction-capable hydrocarbons, aerosols, contents of lead, mercury, arsenic, and cadmium, and, in keeping with the World Meteorological Organization (WMO) program, sodium, chlorine, and sulphates; in atmospheric fallout and precipitation, DDT and other organochlorides like polychlorbiphenyls lead, mercury, arsenic, cadmium, and, additionally, in keeping with the WMO program, sulphates, chlorides, etc.; in natural waters, DDT and polychlorbiphenyls, lead, mercury, arsenic, cadmium, and additionally, in marine waters, oil products; in soils and in the biota, DDT and polychlorbiphenyls, lead, mercury, arsenic, and cadmium.

Observations will include a standard monitoring program for accompanying factors (hydrometeorological and climatological observations) necessary for decoding these observations on the level of the contamination. These independent indicators of environmental quality will be conducted at regional and baseline stations, including the biosphere reserves.

It seems that an important condition for background monitoring is to secure not only integrated observation, but also information of the circulation of the above-mentioned substances. This aspect places great demands on the organization of observations, taking into account the intralandscape migrational relationships. The idea to establish a bank of representative specimens for future studies with chronologically reliable material is interesting, though thus far, difficult to implement.

It should be noted that the above-mentioned list of substances for baseline monitoring is not fixed once and for all and may be revised as our knowledge on the global distribution of discharged substances increases. To have the scientific background to do this, it is necessary to have studies at some of the regional and baseline stations. The first toxicant is most likely benz-a-pyrene which is both interesting itself and as an indicator of other hydrocarbons of anthropogenic origin.

Thus, the organization of biosphere reserves, and the elaboratio of the theoretical and operative working programs in them should be an essential stage towards regulating the quality of environment

Anthropogenic Transformations of Natural Ecosystems and Their Study at Biosphere Station-Reserves

by

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1. The section about the tasks of station-reserves in the general report on the system of biosphere reserves in the U.S.S.R., compiled by Izrael et al. (1975) indicates that one of their basic tasks is the "continued, regular, and focused studies of various ecosystems to develop scientifically valid parameters of controlling the state of environment and their importance for man's well-being."

2. We emphasize in the above paper that the main attention should be given to biotic components of ecosystems, since they are primarily the objects of anthropogenic influence and are the most sensitive indicators of changes in environment. At the same time, the study of biotic components should be conducted first of all on the so-called ecosystem (biocenotic) level and supplemented by studies on the physiological and genetic levels of the species. The main attention on the ecosystem level should be given to: (a) the identification of the biota's composition and its changes under anthropogenic influences; (b) the observation on the functional vitality of producers, consumer and reducers in different ecosystems; and (c) the identification of the levels of primary and secondary productivity, etc. The main attention on the species' level, most likely, should be given to the population dynamics of indicator (key) species of plants and animals; on the physiological level, to the photosynthesis, respiration, growth, and reproduction of the biota; on the genetic level, to mutagenesis, teratogenesis, etc.

It is indispensable that the study of biotic components should be related to environmental factors and, primarily, the radiation balance on the territory, its thermal and hydro regimens, etc. It is also necessary to insure that such a system of observations would make possible the transformation of the primary above-mentioned parameters of environments into appropriate parameters for the studied ecosystems (for instance, microclimate) and vice versa.

Finally, alongside the biotic and abiotic components, the biosphere stations (reserves) should observe indicators of different developments and processes in ecosystems which are the result of environment-biota interaction. Priority should be given to observations on soil dynamics (the thermal and hydro regimen,

gas composition, and changes in reactions). This set of observations should include biogeochemical studies of the circulation of the most important nutritive and biogenic substances and their anthropogenic transformations.

3. In general, the range of consequences and products of anthropogenic influences on natural ecosystems should comprise a particularly important area of observation at biosphere station-reserves in their "buffer" or native zones. At the same time, the observed objects should make up a consistent series of ecosystems. The ecosystems should range from primary links--natural ecosystems which are subject to relatively weak anthropogenic influences (like exploited forests; pasture and mowing lands, plowlands where conventional farming methods are used; recreational territories; etc.)--to wastelands, on the one hand, and the natural-cultivated ecosystems, on the other hand, which have experienced specificially profound anthropogenic transformations (for instance, forest plantations, parks, ameliorated plowlands, artificial meadows, etc.). It should be repeated that tracts or plots of preserved natural ecosystems, typical for the given natural region and strictly protected under reserve status, should be used as a reference base for changes that have occurred or are occurring.

4. As was indicated earlier, the main task of these observations and studies should be the development of scientifically substantiate parameters for the broadening of observations and control over the state of environment (monitoring). It is known that the most widespread indicators of this monitoring are the toxic indicators of air and water pollution and also contamination of soil; i.e., the so-called indicators of the maximum allowable concentration (MAC) of certain substances discharged into the environment with industrial and domestic waste, pesticides, etc. It is known that such indicators or quotas are, and should be, related to man. It is clear that their list may be and should be extended, however, either on the strength of their toxicity or because of other forms of influence they have on many species of plants and animals. This is also necessary because many such substances enter the trophic chain in the processes of agricultural production, livestock breeding, fishing, etc.

When the task is formulated in this way, however, it becomes necessary to comprehensively study the range of trophic and other relationships in natural and natural-cultivated ecosystems, i.e., include their study in ecological programs at biosphere station-reserves which are being considered.

5. It is likewise necessary to consider that the determination of the environment's natural ability to autoclean (ACA) is essential for the proper ecological evaluation of indicators or quotas of the MAC of pollutants. This ability is also predetermined by the existence of definite trophic and other (biogeochemical) relationships among the components of natural ecosystems and also of a definite volume and intensity of natural biological circulation of substances. Therefore, when we introduce into the parameters of ecological observations at biosphere station-reserves the indicators of ACA,

we cannot only state the "excess load" of pollutants and other substances on natural ecosystems but also determine (forecast) the maximum allowable load (MAL) on one or another ecosystem (including the natural-cultivated) of different domestic and industrial waste, with which the given ecosystem can more or less cope thanks to its ACA. It is apparent that the indicators of ACA and MAC should be studied and determined by comprehensive investigation of trophic relations and intensity of the biochemical circulation of substances in the main types of natural ecosystems in separate river basins and different types of reservoirs.

6. The most important results of ecological studies at biosphere station-reserves should be the identification of the levels of efficiency of utilization of natural resources of the biosphere and the changes in natural and cultivated productivity of ecosystems under the influence of various technical measures. One of the most important properties of natural ecosystems is their biological productivity (BP). Therefore, we believe that the ecological studies at biosphere reserves should include indicators of BP both for natural and manmade "natural-technical" ecosystems (agricultural systems, forest plantations, etc.). The comparison of these indicators will make it possible to determine the levels of effective utilization of a number of natural resources (climatic, terrestrial, aquatic, biologic, etc.) expressed in accurate quantitative parameters. This will make it possible to go over from conventional empirical and statistical norms of different technical measure (agriculture, forestry, amelioration, etc.) to scientifically substantiated and predictable utilization efficiency factor (UEF) for various types of natural resources.

7. I believe, however, that the determination of the intensity and the character of anthropogenic influence upon natural ecosystems should not be confined to the above-mentioned factors (MAC, MAL, ACA, and UEF). Most important at present is quantitative "demonstration" of the widespread notion of the existence of a natural ecological equilibrium whose disruption leads, as they say, to the "devastation" of nature. Essentially, these expressions denote a radical destruction of natural ecosystems. This destruction is due to cardinal changes in the natural flows of energy and matter and the disruption of the dynamics and balances formed through ages of evolution. There emerge and develop irreversible phenomena which exceed the limits of "stability" (specifically the MAL and ACA) and which lead to the dislocation of the entire ecosystem. The instances of this type are plentiful. We can mention the accelerated processes of the soil erosion which take place when the natural water balance is disrupted or in case of deforestation or excessive plowing of water drainage territory; and eutrophication ("blooming") of water reservoirs, which arises when surplus volumes of so-called nutritive substances flow in from the surrounding water discharge areas.

8. A question arises, however, have we at the present time a sufficiently developed scientific approach and the techniques for studying the processes of similar disruption of "ecological equilibrium" in natural ecosystems and their radical "devastation" owing to

anthropogenic influences? This is followed by another even more specific question: Are we in a position to use at biosphere station-reserves a method of identifying the intensity of anthropogenic influence on natural ecosystems taken as a whole? I can give a positive answer to these questions with a great deal of certainty. I have in mind those suggestions related to the techniq of studying the internal circulation of substances in natural ecosystems and the relevant dislocations which were suggested by us (I. P. Gerasimov, Y. A. Isakov, and D. V. Panfilov) in the form of systems of so-called structural-functional indicators.

9. At the moment, out of a system of such indicators, I shall single out three, for the sake of simplicity. These indicators are: (a) the balance of biological production (the relation of primary and secondary BP); (b) the rate of formation of biological production (the relation of annual primary and secondary biological production to the overall biomass); and (c) the intensity of the circulation of substances (in i.e., the disportion of mobile substances incorporated into the biological circulation reserve in relation to their general stock.

I shall not go deeper into the explanation of these indicators. It should be mentioned only that they are based on the characteristics of the processes of creation, utilization, destruction, and residual accumulation of biological production (primary, secondary) in ecosystems of different categories and the circulation of substances involved in the biological circulations. Thus, the above-mentioned functional-structural indicators describe the most general and essential phenomena, characterisitic of natural ecosystems and which determine its internal matter-energy dynamics.

This can be explained by the known example of the so-called trophic matter-energy pyramid (the relationship of producers, consumers, reducers and their production in natural ecosystems). This figure in itself can symbolize an ecologically balanced natural ecosystem or be its graphic model. Different types of functional structure of climax natural ecosystems differ by size and some other peculiarities of their graphic representation; nevertheless, all of them belong to this type of equilibrium model. This is easily seen if one uses or inserts concrete quantitative characteristics for different types of climax ecosystems (for instance, forest, steppe, desert, etc.) into the basic graphic scheme of the trophic (matter-energy) "pyramid."

The graphic models built in keeping with the functional-structural indicators have an absolutely different effect (not to speak of the sizes) both for succession ecosystems and for ecosystems altered under anthropogenic influences. The equilibrium of the main elements of functional structures is disrupted (to varying degrees) in all of them. For instance, the level of primary biological production compared with the secondary production is disproportionately large, the stock of residual production is disproportionally depleted, or secondary production is catastrophically small. This shows clearly the disrupted "equilibrium" of such systems and it is expressed in different

deformations of the appropriate graphic models. It is likewise clear that such deformations might be readily described in a mathematical form.

To elucidate these suggestions, we present a basic chart of anthropogenic disruptions of natural ecosystems due to forestry, agriculture, and animal husbandry (fig. 1).

In conditions of forestry (without aforestation) we extract from natural forest ecosystems definite volumes of residual biological production (wood). In this way we disrupt (deplete), first of all, the volume (intensity) of the natural circulation of substances. This leads to the weakening of biogenic circulations which maintain the natural level of primary and secondary biological productivity. Consequently, its reduction results in disruption of the natural balance and rate of formation. Subject to the extent of this extraction, the disruption of the ecological balance in a natural forest ecosystem may vary, leading even to its complete destruction.

Under the conditions of farming, we first liquidate all the surface residual biological production in a natural ecosystem and then go on to remove annually a considerable part of the primary biological production. The first action violates the intensity (volume) of the circulation of the biogenic substances which, however, is amply compensated by the introduction of nutrients (manure, fertilizers, etc.). This insures an intensification of the biogenic circulation of substances which is indispensable for an increase in the primary biological productivity (harvest). Considerable annual withdrawals of this production, however, cause a reduction in secondary biological productivity and the weakening (liquidation) of the return of substances to biogenic circulation. As the result of all these alterations, we see a disruption both of the natural balance of biological production and the rate (volume) of the formation of its residual part. Subject to the volume of the liquidated surface residual biological production, the size of annual withdrawal of primary production, and the artificial increase in biogenic substances, the extent of the disruption of ecological equilibrium in a natural ecosystem used for farming needs might vary. The appropriate characteristics of these disruptions (including the above-mentioned structural-functional indicators) might be fruitfully applied to determine the utilization efficiency factors of some land resources (soil types).

Under circumstances of grazing and livestock breeding, we withdraw from natural ecosystems certain volumes of secondary biological production. This weakens the return of biogenic substances into circulation. At the same time, we seek to increase secondary biological production. This calls for an invigoration of the biogenic circulation of substances and definite links (at the expense of others) and results in a reduction of the primary (pasture degression) and residual biological production. All this leads to a disruption of the natural ecological equilibrium in the ecosystems which are used

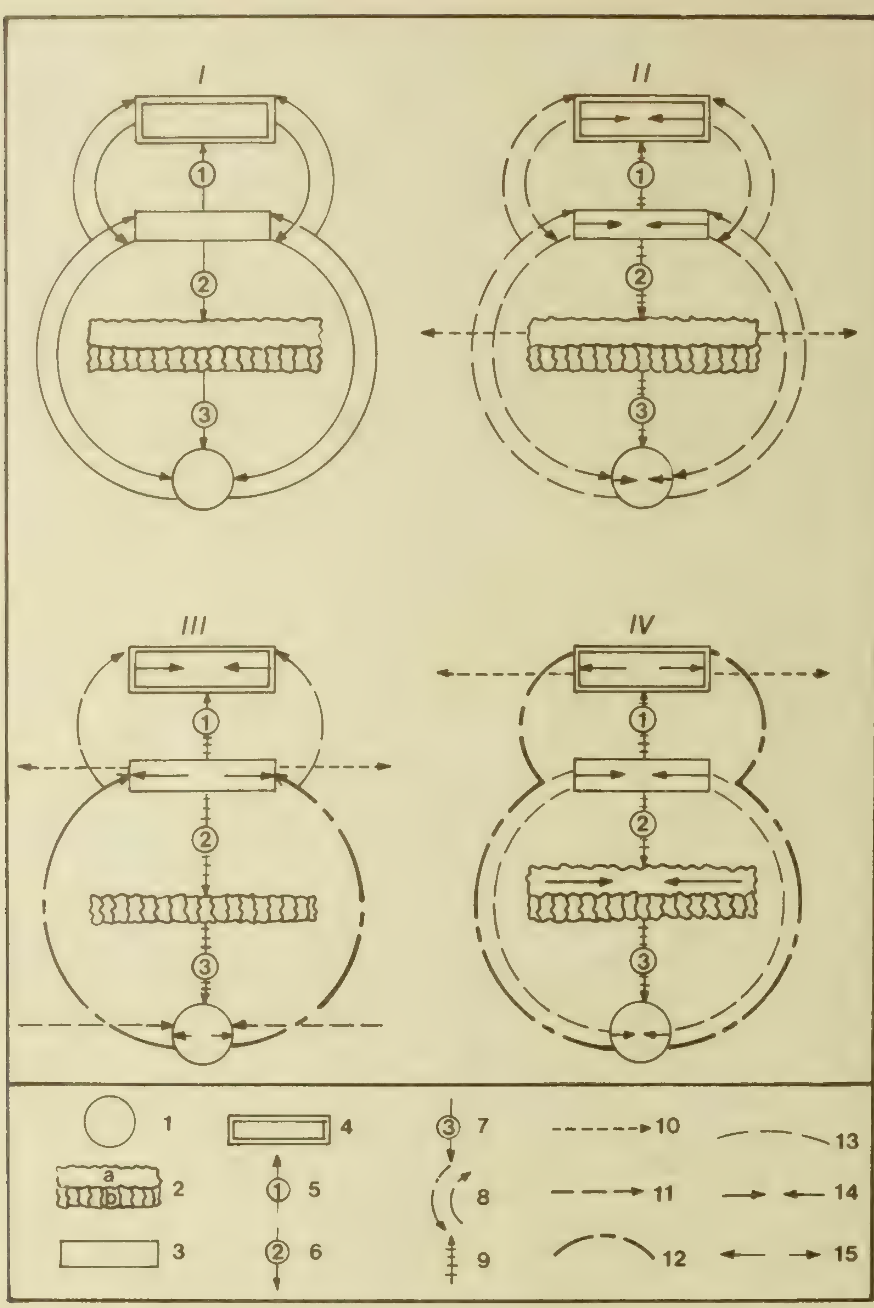

Figure 1.— Principal types of disturbance of natural, balanced ecosystems: 1-Mobile biogens, 2-general biological mass and reserve in mass (a) surface, (b) subsurface, 3-primary biological production/annual, 4-secondary biological production/annual, 5-balanced biological production, 6-rate of formation of biological production, 7-intensity of substance circulation, 8-biogenic circulation of substances, 9-disturbance, 10-removal, 11-introduction, 12-intensification, 13-weakening, 14-diminution, 15-increase. Principal anthropogenic disturbances of a natural balanced ecosystem: (I) under forestry conditions, (II) without afforestation, (III) in farming, (IV) grazing.

for livestock breeding and is expressed in different structural-functional indicators (including those used in our models).

10. The above-mentioned approach to identifying functional structures of natural ecosystems and their anthropogenic deformations has been presented in a number of publications and in a symposium on biosphere reserves.

There is the possibility, at present, to use this approach on a larger scope with regard to local variants of natural and native-cultivated ecosystems. This is possible for forest-steppe ecosystems, using materials representing many years of observation in the central forest-steppe of the Russian plain (Kursk Experimental Station of the Institute of Geography, U.S.S.R. Academy of Sciences); as for taiga ecosystems, we may use mainly the data accumulated at stationary installations of the Institute of Geography and the Institute of Forest and Timber, U.S.S.R. Academy of Sciences (Baikal area), and of the Institute of Deserts, Academy of Sciences of the Turkmen S.S.R., for desert ecosystems at the Repetek station. I believe that precisely these districts are of specific interest at present since all of them belong to the projected Soviet network of biosphere stations which has been suggested in the general report of Izrael et al. (1975). I trust that we will be in a position to report some results of this type of a study program at the next symposium devoted to biosphere station-reserves.

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Research at U.S.S.R. State Reserves and Their Role in Monitoring Biosphere Changes

by

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State reserves in the U.S.S.R. hold a leading place among territories singled out for the preservation of biotic plant and animal associations within the areas of natural ecosystems and for protecting genetic diversity of species. By their objectives, established regimen, and functions state reserves differ from National Parks, relics of nature, wild animal reservations, and the so-called primitive regions and other administrative forms of protected natural territories in the United States. (In other languages, apparently, there is no true synonym for the term "zapovednik", which adequately and accurately conveys the specifics of this form of protection and study. Rather than attempting to use analogous concepts, it would be better to adopt its transcription.)

The idea of state reserves is to preserve typical areas of the main biogeographical subdivisions of the national territory with their natural diversity of plant cover and the animal population peculiar to these subdivisions. The reserves are completely withdrawn from all forms of tourism, recreation, and economic utilizatio including timber-cutting or hay-mowing. The network of reserves represents a system of reference types of zonal and provincial landscapes which are necessary for comparison against the territorie which are used for economic purposes and are ecological models for the restoration of natural ecosystems.

The Soviet Union has 130 state reserves, their total area exceedi 9 million hectares. They are located in the Arctic, tundra, taiga, mixed and broadleaved forests, in the forest-steppes, steppes, deserts, in mountain systems and in maritime zones. Most frequentl a single reserve covers an area of 30 000-70 000 hectares; however, there are reserves with an area of 700 000-900 000 hectares; some, located in the densely populated districts, cover less than 5 000 hectares.

Reserves play an important part in preserving and reproducing many species of animals and plants, including those on the verge of extinction. It is evident that under contemporary conditions, the protection of living species, the preservation of our planet's gene-pool, can best be achieved by protecting natural habitat, as i reserve territories. It is precisely in this way that in the U.S.S.R. many examples of plant and animal life have been preserved examples are the tiger, leopard snow leopard, musquash, European

bison, flamingo, the lotus, pistachio, yew-tree, etc. Thus, when the Barguzin Reserve at Lake Baikal was established, there were about 20 or 30 sables there in shelters in inaccessible rock streams. At present, sables which spread out from the reserve comprise a large population of commercial significance. There were several pairs of beavers at the Voronezh area before the establishment of the reserve. In the 50 years of the reserve's operation more than 3,000 beavers were taken from it and re-settled in 73 districts of the U.S.S.R. These beavers produced 70,000 offspring. Slightly more than 100 wild reindeer had survived in the Kola peninsula within the Lapland tundra area. At present, there are approximately 20,000 reindeer in the Lapland Reserve. It seems that with present conditions, the protection of living species and the preservation of the gene-fund of our planet can be particularly successful by protecting the places of their habitation, beginning with those within reserve territories.

The network of Soviet Reserves is growing regularly. In the last 10 years alone, 30 reserves were established on an area exceeding 3 million hectares; it is expected in the next 5-10 years to establish another 30 reserves on an area approximating 4 million hectares, mainly in the Arctic, taiga, steppe, desert, and in the mountain systems. As the result of this, reserves will represent all the main biomes and biomic subdivisions of our country.

Soviet Reserves are research establishments with an aggregate staff of more than 1,000 associates and specialists. They conduct studies in keeping with coordinated programs; besides this, there is approximately an equal number of scientists from other organizations and establishments of the country working at these reserves.

Reserves have been of great importance as regional scientific centers for integrated nature research. The examination of the regularities of biological circulation and other natural processes of natural ecosystems are particularly successful on the territory of reserves through the participation of their research staffs. The understanding of these processes makes it possible not only to forecast the results of the anthropogenic transformation of natural ecosystems, but also to find ways of regulating it.

Traditionally, many scientific programs at reserves are devoted to the ecology of individual plant species and animals which were threatened with extinction. Detailed examination of the characteristics of individual species, their habitat pecularities of feeding, breeding, and wintering, has provided a scientific foundation for the elaboration of measures to preserve, restore and wisely utilize the existing stocks of rare animal and plant species. This scientific foundation has been used for the successful preservation, in the U.S.S.R. of 18 species of extremely rare animals, 29 species of rare birds, and of many rare plants. Mention can be made of animals such as the aurochs, cheetah, tiger, leopard, culan, mountain antelope, desman, francoline, flamingo, and eider; as for plants, mention can also be made of the lotus, yew, pistachio, and many others.

The main content of research at reserves is determined by many years of biogeocenological studies. The latter makes in possible to investigate the cycles of intricate natural phenomena which take many years and to follow the changes in the structure of natural complexes. This primary form of biogeocenological observation is referred to as nature's records and is performed in keeping with a strictly defined program, providing for the registration of all conventional and extraordinary phenomena in the reserve. This includes meteorological, microclimatic and hydrological observations, the registration of phenological phenomena, measuring the production of different plant groupings, evaluation of the harvest of plant fruit and seeds, inventory of the number of animals, characterization of conditions for wintering, reproduction and other vital statistics. Nature's records also register the deviations in the state of natural conditions: droughts, severe winters, avalanches, high freshets, downpours, storms, forest fires, epizootics, outbreaks of entomopests, etc. All facts of anthropogenic influence on the reserve's territory are carefully recorded. These include the changes in the hydrological regimen, the entry of synanthropic species, domestic animals, species which became acclimatized in neighboring territories, etc. The consequences of all these events are analyzed, and the restoration of the damaged state of nature is observed. Every year the data are processed for successive publication of nature's record and once in 5 years a consolidated book is compiled. The scientific fund of the reserve also incorporates other materials: photodocuments of landscapes and natural phenomena, maps and diagrams of the distribution of vegetation and reservoirs and other elements of the landscape, the location of bird nests, burrows, bird mating grounds, paths of animals, results of measuring meteorological and hydrological data, of soil-forming processes, the registration of phenological phenomena, animal encounters, and also the collected materials like herbariums, soil or rock monoliths, entomological collections, carcasses of animals, preparations, skulls, etc. Nature's record and the collection of primary scientific data have been collected for quite some time at all reserves in keeping with a uniform scheme; in many reserves the period covered by such data is more than 50 years. These materials, particularly those which cover many years, are of considerable value; and in a number of instances they may serve as the standard reference on natural environment against which we should compare the environmental parameters from areas exploited by man.

Integrated, permanent research programs are based on large-scale maps of topography, soil, water reservoirs, vegetation, forest types, and other physico-geographical conditions, as well as the results of flora and fauna inventories and materials covering the history of the territory which are available at the majority of reserves. This information is used to select districts of location, contours and routes of permanent profiles, transects, permanent recording plots, pheno-stations, and other stationary establishments which reflect the main aspects of natural conditions in a reserve: latitudinal zonality, altitudinal zonality, types of vegetation, diversity of topography, age variation, etc. The system of permanent observation sites is built in order to obtain information which is sufficiently representative with regards to the studied plot and

which allows the findings and survey material to be extrapolated to an appropriate region. A permanent profile characterizes the natural complex of the relevant district and is the key plot for studying seasonal, annual, and long-term changes in nature. The permanent observation plots are used for geodetic survey, a detailed description and mapping of the soil cover and vegetation is carried out, the mesofauna and other indicators which are on the program of the integrated biological inventory are recorded (biosurvey). Such full biological surveys are repeated, as a rule, every 5 years and make it possible to monitor the variablity of structural characteristics of the cenosis: The growth and development of cenosis-forming species, the dynamics of growth and dying off of different pheno-rhythmotypes, the rhythmicity of the bioproduction process in the cenosis, the variability of indicators at different levels of the cenosis, and other parameters. Besides the annual biological surveys, there are regular observations of the components of the biocenosis as well as seasonal changes in a number of enviornmental factors including the rhythmicity of some characteristics. These are conducted along the profile and at permanent observation sites. They include hydrological and hydrogeological observations, snow surveys, the study of the circulation of nutritive elements and their loss with runoff waters, the determination of the biological productivity of censosis, ecological-physiological studies, etc.

The indicated methods of integrated permanent studies make it possible to discover and appraise the structure, the laws of functioning of ecosystems including the quantitative and qualitative relationships within the ecosystem components, the succession stages, time periods for restoration, the ability for a given standard of productivity, and other characteristics.

Permanent monitoring of the animal populations is also conducted along pathways of regular movement, at places of their regular accumulation, and on other plots where comparable and continuous results can be obtained. It is difficult, however, to speak of techniques for using this type of data for a full population characterization of species which are very mobile and migratory.

Permanent biogeocenological studies are well developed at some reserves of the Soviet Union. The Caucasian Reserve has included, in a network of integrated permanent sites, all representative and unique phytocenoses in the areas of populations of most important relict forest-formers in the three meridional ecological-geomorphological profiles spaning the Main Caucasian Ridge (vertical zonality-from 600 to 3 200 m). A similar system of permanent, integrated observation sites has been established in Sikhote-Alin, Altai, Teberda, and some other mountain reserves. A diversified network of integrated biocenological permanent observation sites has been established at the Voronezh, Central-Forest, Khoper, Oka, and other lowland reserves.

Monitoring the state of the plant cover at the comparatively small Priokso-Terrace Reserve is based on a system of permanent observation sites combined with regular detailed territorial examinations which make it possible to trace changes in different types of successions and fluctuations over many years.

The integrated studies at permanent observation sites at the Astrakhan Reserve conducted for many years on ecological-geomorphological profiles in the Volga river delta and in the coastal band of Northern Caspian provide interesting data on the hydrogeological regimen, geomorphological characteristics, and present state and the changes in the hydro- and land-surface vegetation. They also provide data on aquatic and terrestrial animals in the periods prior, during and after establishment in the conditions of a regulated Volga river discharge.

In order to better evaluate and manage ecosystems and to find methods of early diagnosis of ecologically significant changes (pollution) of the environment and biosphere, studies of bioconcentrating and sensitive indicator species of plants and animals are conducted in a number of reserves. The Central-Forest Reserve is using contemporary ecological morphology and physiology of plants to evaluate the state of the plant cover in the taiga biota. The associates at this place make use of these species which are decisive in the plant cover. The sensitivity of coniferous species to atmospheric pollutants makes it expedient to study the structural and functional characterisitics of spruce trees which might be of indicator significance.

The associates of the Caucasian Reserve are collecting data on the reproductive and regenerative ability of the cambial activity and other bioecological properties of some plants which are sensitive to environmental changes.

The soil fauna and insectivorous predators are studied among the organisms studied as possible model indicators by the associates of the Central-Forest Reserve. The idea is that the state of soil-inhabiting invertebrates, which are characterized by their close relationship with the physical and chemical regimens of soil, might be used for recording the influence of different soil pollutants. Soil fauna include animals at different trophic levels, and this affords the possibility of evaluating the effects on and dynamics of number, fertility, population structure, etc.

The state of insectivorous predators, while consuming other species which cummulate definite pollutants, may also give information on the circulation of these substances in nature. The short life cycle, intensive metabolism, and lability of the main morphological and physiological indexes of shrews makes them a particularly attractive indicator species.

The studies in some reserves cover the behavior of individual radionuclides in the biological circulation of matter and their action upon the growth and development of plant and animal organisms. Several animal species have been singled out for their active cummulation of radionuclides and as possible indicators of this type of environmental pollutant.

CONCLUSIONS

The content and the orientation of research at Soviet state reserves makes it possible to consider the reserves as unique natural laboratories which possess a network of native "instruments", native "proving grounds", which are sensitive to any changes in the biosphere. Scientific work at reserves is subordinated to the task of obtaining information on the state and dynamics of natural systems and their components under different conditions of development. It is conducted by continuous and periodic studies on the state of the environment and elements of the biosphere. A system of permanent biological observation sites, which reflect the diversity of natural conditions, ensures the reliability of averaged indicators for the entire territory of a reserve and their adequate representativity as related to the biome.

The network of state reserves in the U.S.S.R. which are located in the main biomes of the country might be used for the investigation of the influence of pollution on terrestrial and fresh water ecosystems and for monitoring the level and behavior of pollutants in the selected components of those ecosystems.

The state of the environment--air, water, soil, etc--at most of the reserves is still not being recorded completely in accordance with basic and unified indicators which provide for the identification of the necessary parameters of pollution. The state, distribution, and population dynamics of the main species of animals and plants, in most reserves, however, has been studied in keeping with a uniform program for 30-50 years. Some of the reserves have singled out individual indicator species of those animals and plants which are most labile and which respond actively to environmental changes, therefore making it comparatively easy to record the changes in their organisms.

The organizational structure and management of reserves provides for territorial zoning and differentiated operating conditions, ensuring: (1) the maintenance of natural processes in a considerable portion of the territory; and (2) the possibility of implementing measures for the protection, restoration, and regulation of disturbed natural relationships.

The regimen at reserves and the zonal-geographical principle of their location throughout the country ensures the advantages for the organization of monitoring the background state and changes of the biosphere in the given region. The main task is not the formulation of the techniques of biosphere studies because new methods might be developed at reserves; the most important thing at this moment is to establish a system of biosphere reserves as the foundation for the studies and for the preservation of the genetic diversity of the biosphere.

It should also be noted that the term "biosphere reserve" should not be applied to territories without reserve status. The varied forms of monitoring stations are not identical with the content of operation of biosphere reserves and cannot be expected to replace them.

Research at Biogeocenological Stations in Deserts — A Link in the Biosphere Monitoring System

by

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Deserts in the Union of Soviet Socialist Republics (U.S.S.R.) cover a vast territory of 200 million hectares--approximately 10 percent of the country's total area. This is mostly virgin territory where natural resources have not been fully developed.

Varying natural conditions of the arid region are represented by different types of deserts. A network of biogeocenological stations sufficient to encompass the diversity of at least the main subdivisions of the desert biome would be the ideal situation. This is, however, often not the real situation. Also, although there is a rather large network of stations in the arid zone of the U.S.S.R., not all of them conduct biogeocenological research (table 1).

Table 1--Biogeocenological stations and permanent desert monitoring stations in the U.S.S.R.

Location, Name, and Natural Conditions	Year Established	Agency
1. Repetek-Desert-Sand Station with a "Zapovednik". Eastern Kapakums, white and black haloxylon.	1912	Institute of Deserts, Academy of Sciences of the Turkmen SSR.
2. Karakum Station/Karra-Kul/Takyr Range of the Central Karakums. Large shrub associations in sands and semi-shrub associations in the Takyrs.	1960	Institute of Deserts, Academy of Sciences of the Turkmen SSR.
3. Tereskent Station, Northern Arals, wormwood in greyish-brown soils, sand.	1965	Institute of Botany, Academy of Sciences of the Kazakhstan SSR.
4. Takum Station. Southern Balkhashes Shrub and grass associations in sand.	1965	Institute of Botany, Academy of Sciences of the Kazakhstan SSR.
5. Kizilkum Station. Western Kizilkum. Shrub and semi-shrub associations in gypseous desert.	1959	Institute of Botany, Academy of Sciences of the Uzbekistan SSR.

The deserts are an arena of highly specialized life under extreme conditions, conditions near the limit for possible existence of developed communities. At the same time, deserts are areas where the potential biological productivity of biogeocenoses is rather high. Therefore, it is an urgent task to understand the laws of life in the desert zone so that this information can be used as a baseline in developing integrated biological systems for amelioration and rational use of biological resources of the desert.

SPECIFICS OF DESERT BIOGEOCENOSIS

The following features of desert biogeocenosis are important distinguishing features: (1) environmental peculiarities, particularly the climate (abundance of solar energy, high temperatures, scarce precipitation, etc.); and (2) the peculiarities of biological cycles of ash elements and nitrogen, due to the rapid decomposition and mineralization of organic detritus in a situation where there is practically no litter and humus accumulation is negligible.

The biogeocenosis includes most varying forms of plants, animals, and microorganisms with different adaptations to unfavorable environmental conditions. The entire life of biogeocenosis goes under extreme conditions, with very sharp variations in the differing factors. Seasonal and annual fluctuation of all vital processes are pronounced. A definite part of the territory occupied by a developing biogeocenosis, particularly in the sand desert ("barkhan" sands).

The desert biogeocenoses, have had a long history of formation. They represent mature self-regulated systems with strongly interlinked biotic and abiotic elements. These connections maintain the long-term existence of biogeocenosis within definite average parameters. The unavoidable, and sometimes considerable, variations in total productivity ususally level out rather quickly and the entire system soon approaches the average value.

It is of utmost importance to determine the average values of a number of parameters for many years (the number of plant and animal species, their biomass, etc.). It is also important to ascertain the reasons for both their average fluctuations and limits. For example, since vegetation is used as livestock feed, it is important to know the size of crop yields for various types of pasturage and their annual fluctuations. It has been established that all phytomass production and year-to-year fluctuations, due to meteorological factors, are linked to the composition of vital plant forms on various types of grazing land. The general phytomass (dry weight, kg/hectare) of large-shrub associations makes up 80.7 (surface-37.5, subsurface-43.2); small-shrub associations 51.2 (surface-28.0, subsurface-39.4); semi-shrub associations 51.2 (surface-32.5, subsurface-18.7); grass associations 29.2 (surface-4.5, subsurface-24.7). Thus, vegetation cover, consisting of highly organized biomorphs, seems to be most productive (fig. 1).

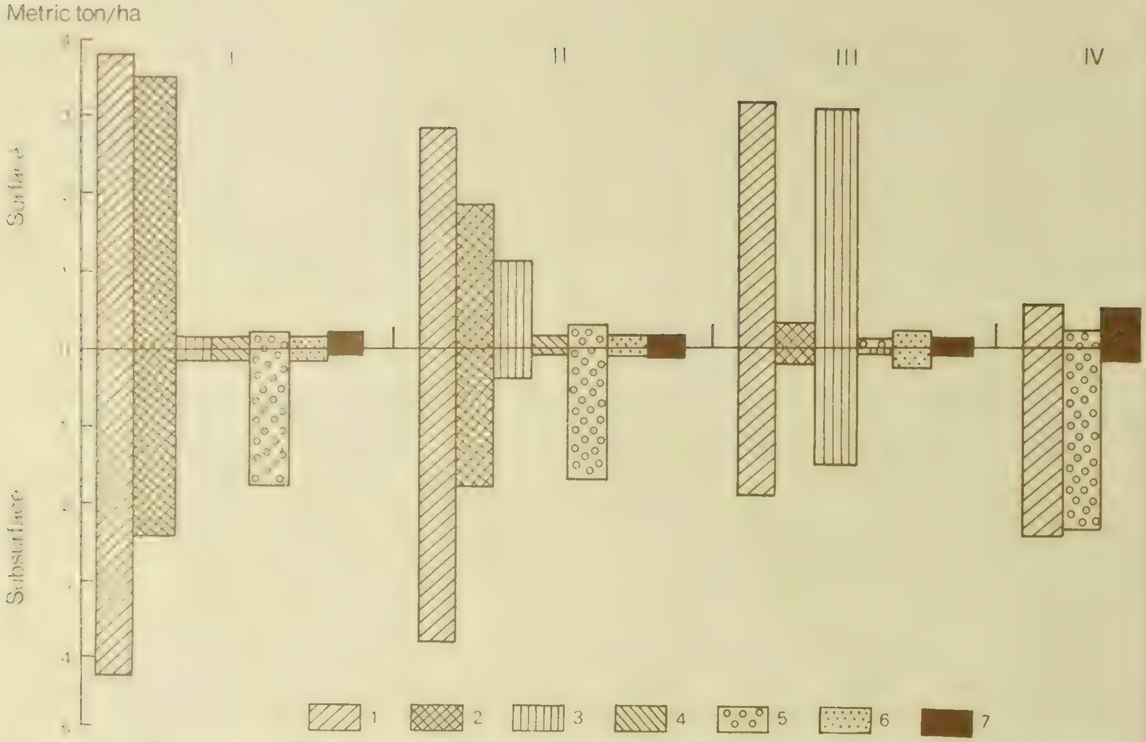

Figure 1.—Phytomass structure of desert phytocenoses, related to vital form content. I—Large shrub associations *(Haloxylon persicum – Carex physodes* ass.); II—Small shrub *(Salsola arbuscula-Artemisia, kemrudica-Carex physodes* ass.); III—Semi-shrub *(Salsola gemmascens + Artemisia kemrudica* ass.); IV—Grasses *(Carex pachystylis + Poa bulbosa* ass.). 1 — Total phytomass; 2—shrubs; 3—semi-shrubs; 4—perennial summer-fall grasses; 5—perennial winter-spring grasses; 6—annual summer-fall grasses; 7—annual winter-spring grasses.

Long-term average yields of annual sprouts (feed) is close for all types and comprises 4.7-4.5 kg/h, while year-to-year changes, due to weather conditions, are varied: they are less pronounced in shrub associations, where species with well developed perennial surface organs dominate, and more significant among the grasses (fig. 2). These patterns have great significance for desert animal husbandry, based mainly on natural grazelands.

Induced disruption of the biogeocenotic links, such as a sharp intensification or weakening of any component, invariably causes certain rearrangements within the biogeocenosis; the intensity of the readjustment increases with the importance of the altered factor in the life of the biogeocenosis.

Biogeocenoses are subject to regular changes owing to their natural age; the most essential present changes, however, are those depending on anthropogenic influences. At the present time,

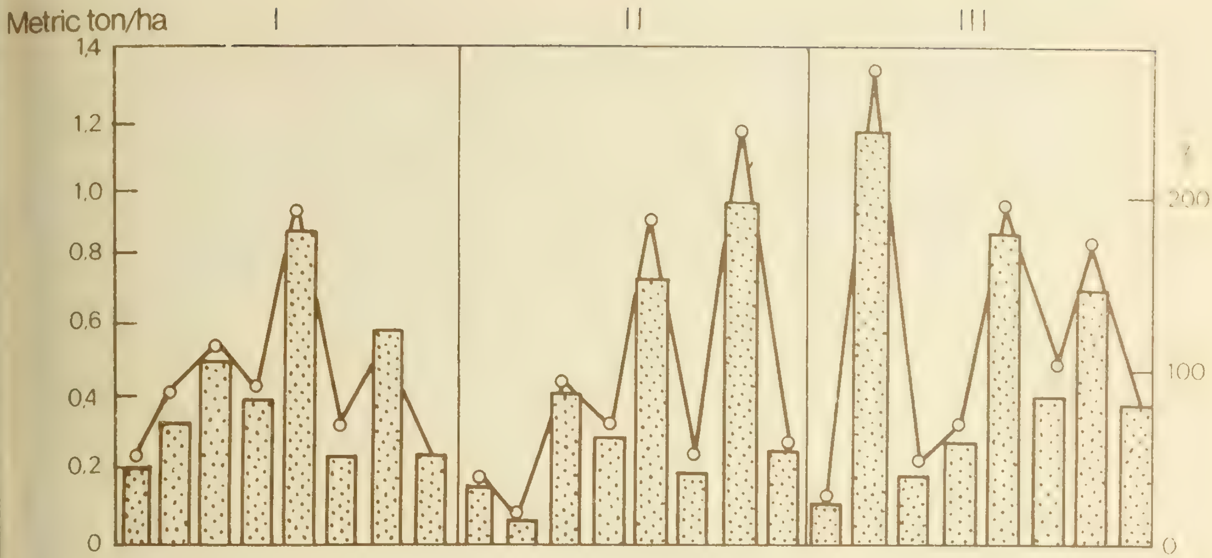

Figure 2.—Crop Dynamics (1960-1967). I—Large shrub associations *(Haloxylon persicum-Carex physodes* ass.), M = 0.47 (100%), lim = 0.26-0.92 (55-195%); II—Semi-shrub *(Salsola gemmascens + Artemisia kerudica* ass.), M = 0.45 (100%), lim = 0.08-1.05 (17-234%); III—Grasses *(Carex pachystylis + Poa bulbosa* ass.), M = 0.45 (100%), lim = 0.13-1.23 (29-273%). Columns = harvest, T/h; Curve - harvest fluctuations (%).

all deserts are undergoing rapid changes owing to intensive geological and hydrological surveys and mechanized development of mineral resources.

Engineering staffs, unaware of desert ecology needlessly destroy nature. Examples of this are the numerous unwanted roads built in deserts and the destruction of takyr surfaces by motor transport which has disrupted their role as water drainage systems. Excessive cattle grazing and shrubcutting for fire wood cause considerable disruptions. All this is due to underestimating the sensibility of desert ecosystems which function in extreme conditions and are extremely responsive to quick and irreversible changes.

The structual transformations of biogeocenoses, due to economic utilization of desert territories, has to a considerable degree superceded in both speed and intensity evolutionary changes of the biosphere; in some instances this activity produces catastrophic consequences. However, technical means in a planned socialist economy afford great possibilities for developing desert zone resources and for realizing scientific management in the economic exploitation of deserts. These great and urgent scientific tasks place the integrated, biogeocenological study of desert ecosystems as a first priority.

MAIN TASKS OF BIOGEOCENOTIC STUDIES

Understanding the operational mechanics of biogeocenoses as single systems is imperative as the danger of disrupting the natural equilibrium in an arid zone is approached.

Integrated biogeocenological studies offer the theoretical basis for developing rational management techniques. This knowledge of natural ecosystems makes it possible to avoid sharp, undesirable, and in many cases, irreversible dislocations as well as to work out techniques for active and meaningful intervention into biogeocenoses for their enrichment and increased biological productivity.

Since times immemorial the deserts have been used as pastures and desert shrubs as sources of firewood. However, the balancing of consumption and conservation of natural resources has not been accomplished.

Domestic animals, specifically sheep and camels, graze the deserts throughout the year and together with wild fauna, are consuming food resources. Cattle influence ecosystems more than wild animals by removing more vegetative mass, introducing their own by-products, and mechanically influencing the pastures. Domestic animals in the arid zone should, therefore, be regarded as ecosystem components equal to wild animals and as the main consumers of primary production. The long-term task of increasing the productivity of pasture-based livestock cannot be solved without theoretical studies based on the anlysis of the consumption of the vegetative mass by different animal species--both wild and domestic.

Biogeocenological studies are based on long-term observation and experiments at permanent stations. The station-based studies of recent decades have greatly contributed to national economy. Rational methods have been developed for the use of grazing lands, improvement of pastures, yield forecasting, improvement of non-irrigated meadows, techniques of fixing and aforesting sands, melioration of mountain slopes, suppressing natural foci of infections, etc.

One of the main ways to conserve natural resources on deserts is to use rational methods for livestock breeding and for extraction of mineral resources. It is understandable that Reserves, which are necessary for the protection of valuable species of animals, plants and intact landscapes, cannot cover very large areas.

It should also be noted that the protected natural landscapes are not always the most productive ones. Moderately grazed territories frequently produce large amounts of plant mass and are known for good plant reproduction. Improved pastures, even without irrigation, have much better yields than Reserve territories. Nevertheless, Reserves are most convenient and indispensable for the protection of rare species of plants and animals and for theoretical research. They serve as reference points for the

productivity of biogeocenoses under different utilization regimes. The biogeocenological studies at all stations should be conducted in keeping with the following pattern: Reserve--anthropogenic variants--cultural biogeocenoses or agrocenoses (irrigated or nonirrigated). Comparative studies of ecosystems under different conditions will more quickly produce recommendations for practice.

PROGRAM OF BIOGEOCENOLOGICAL STUDIES AT THE STATIONS

The study of vital biogeocenotic processes is recognized as a pressing scientific task. The understanding of the structure and functioning of biogeocenoses as self-regulated systems--as fundamental subdivisions of the biogeocenotic cover--is the theoretical foundation for the rational utilization and conservation of the earth's biological resources.

Modern scientific and practical requirements necessitate the study of the entire set of measures relevant to rational utilization, conservation and enrichment of desert ecosystems. Naturally, the major branch would be livestock breeding. Other important aspects are sand fixation, planting of greenery in industrial districts, the special nature of desert forestry, etc. Comprehensive knowledge of the biogeocenosis is indispensible for all these measures. The study of all components of biogeocenoses, and of the balance of element circulation, is most difficult and requires the participation of different specialists. Therefore, attention should initially be drawn to the comparatively simpler questions of secondary and primary productivity.

The main sections of a study program at biogeocenological stations in the desert zone should be as follows:

1. Structural-functional organization of natural biogeocenoses under different utilization regimes. This includes the study of: (a) The matter-energy resources. It should be stressed that the consideration and evaluation of special environment features of living organisms in biogeocenoses is particularly important. This is because of the diversity of ecological conditions, including the great variety in the mechanical and chemical composition of soils and parent rock and the considerable range and sharp annual and seasonal fluctuations in climatic conditions. The products of a biogeocenosis (phytomass, zoomass, etc.) and its life are totally dependent upon a set of interrelated natural factors. These relationships are poorly known and are much more complex than it is sometimes believed. (b) Biological resources. This is an extremely important division of study which helps to evaluate the biotas (the living component) of biogeocenosis with regards to their modal composition, bioforms, and adaptation to arid conditions with consideration for energy and metabolism.

Understanding the structure and productivity (primary and secondary) of natural biogeocenoses in their seasonal and annual dynamics are included here. This covers the study of: pasture reaction (vegetation and soils) to grazing; changes in the species

composition, associations, and productivity; the recreation of vegetation in relation to the influence of grazing upon the soil cover; and the destruction of seeds and sprouts.

2. Elaboration of methods for enriching biogeocenoses. Two methods of increasing biological productivity should be considered-vegetation improvement and faunal enrichment.

Measures for improving pasture vegetation include plant introductions, improved techniques for creating cultivated pastures, seed production, and selection of newly cultivated plants. The improvement of desert pasture with very low precipitation is based on the knowledge of plant ecology and different ways of accumulatin moisture for better utilization of precipitation. An important segment is studying the horizontal and vertical structure of artificial phytocenoses, their productivity, and species composition and structure, as compared to natural biogeocenoses and anthropogenic variants.

A special concern is wind erosion control in sand deserts by using artifical covers and phytomelioration.

3. Rational utilization of pastures. This includes: appraisal of chemical composition and nutritive values of definite types of pasture forage and rations; compositional analyses of wild animals (insects, rodents, ungulates) as well as sheep and camel nutrition; reactions of different plants to shoot removal by animals; and influences of different grazing intensities.

Methods of determining the indices of optimal utilization of pastures and the maximum allowable burden upon ecosystems belong in this area as does improved techniques for pasture utilization under combined grazing of different species of cattle.

Other subjects requiring study are the improvement of pasture rotation systems (alteration of the season of utilization by years) with an optimal load, better techniques for keeping sheep in fenced pastures, the combined utilization of natural pastures with additional feeding of coarse and concentrated foods, and improved systems of pasture use and other techniques for further intensification of desert sheep husbandry.

4. A final section of the research program should be the improvement of domestic animals on the basis of selection, better feeding and keeping of animals, an improved fodder base, better use of remote and poorly watered territories, and the maximum, non-damaging utilization of desert ecosystems.

CONCLUSIONS

The protection of the environment and rational management of biological resources is an important human concern. In the U.S.S.R. both matters are urgent owing to the need to develop sheep breeding and improve productivity.

The study of the man-environment relationship in all its diversity is the substance of the International Man and the Biosphere Program (MAB). The growth of the population necessitates improvement in economic activity to increase the productivity of farmland. To bring this about one should understand the motive forces of biogeocenoses, their dynamics and regulation. The MAB Program should underlie modern agricultural science and practice. As L. I. Brezhnev said in 1974 in Alm a Alta, "Agriculture is in need of new ideas capable of revolutionizing farming production. . ."

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Soil as a Component of Natural Ecosystems and the Study of Its History, Modern Dynamics and Anthropogenic Changes

by

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The study of natural ecosystems at biosphere station-reserves must include the following mutually supplementing directions in soil research:

1. Investigation of the stable, conservative properties (composition and organization) of soil and the soil mantle; actually, this is the study of soil as a product formed over a long period of time due to self-development and evolution of natural ecosystems.

2. Investigation of modern dynamics (functioning) of soil and its anthropogenic changes.

The present paper assumes that biosphere stations will be situated mainly on the territories of natural ecosystems in a dynamic equilibrium with the environment.

In accordance with this assumption, our subsequent reasoning is based on the probable, but not yet proven, concept of a mature or quasi-equiponderant (developed, normal, climax) soil (Kossovich 1911 Rode 1947, Jenny 1948, Gerasimov and Glazovskaya 1960). A mature soil can apparently be only a component of a mature (quasi-equiponderant) ecosystem (Dokuchaev 1964, Sukachev 1972, Rode 1947). This concept is associated closely with the ideas about self-development and evolution of soils.

THE SELF-DEVELOPMENT (MONOGENETIC DEVELOPMENT) OF SOILS

The self-development of soil is understood most frequently as a process of soil body (profile) formation under invariable environmental conditions which start from "time-zero". Complete self-development results in the formation of a mature quasi-equiponderant soil body. The self-development of soil is regarded as a constituent part of the self-development of a natural ecosystem under invariable environmental conditions (Kossovich 1911, Rode 1947, Gerasimov and Glazovskaya 1960, Sukachev 1972, Kovda 1973). The

latter primarily include macroclimate and macrotopography. The formation of a mature soil in different climatic zones is known to require from several hundred to tens of thousands of years. Even within hundreds and thousands of years, however, not all the properties of soils settle into a complete equilibrium with the environment and, therefore, slowly continue to change. But such properties are not of prime significance for the formation of the corresponding type of soil. The mature soils, whose self-development occurred under invariable environmental conditions and, as part of a syngenetically developing natural ecosystem, are called monogenetic (Thorp 1965, Kovda 1973). Time necessary for a monogenetic soil in order to achieve the quasi-equiponderant status is called the relative age of soil (Williams 1950, Gerasimov 1969).

From the viewpoint of biogeoceonologists and ecologists (Sukachev 1972, Odum 1975, and others), a natural ecosystem can be considered mature when its biotic part settles into dynamic equilibrium with the enviornment. But soil - a component of the natural ecosystem - develops more slowly than vegetation and animal life. Even under the influence of a quasi-equiponderant ecosystem, soil continues to develop and move towards a complete equilibrium. Due to feed-back, this results in a slow change of the biome. Thus, a more complete equilibrium of the natural ecosystem occurs with the formation of mature soil.

It is expedient to distinguish between an individual, mature soil profile in a point and the mature soil mantle in a given ecosystem. The latter, along with mature soils, can contain plots of immature, non-equiponderant soils. The immaturity of these soils is regularly maintained by processes organically inherent to the given ecosystem (windfalls, activity of burrowing animals, cryogenic disturbances, etc.).

THE POLYCLIMAX OF SOILS

At present, science recognizes that under similar climatic conditions several climax biocenoses, with their respective soils, are formed. The soil polyclimax results from the fact that soils are formed due to the interaction of equally effective and significant factors of soil formation (excluding climate) such as the topography and parent rocks. This plurality of mature soils (polyclimax) appears under conditions of similar climate in those cases in which there are significant differences in the character of topography and/or parent rocks. In the course of development there occurs a partial convergence of soils developed in different lithological-geomorphological conditions which is never complete.

The above considerations compel one to conclude that in natural ecosystems with similar macroclimate the formation of a certain spectrum of mature soils, rather than one mature soil, is typical.

THE EVOLUTION OF SOILS

In most cases the occurrence of mature monogenetic soils is more myth than reality. There is simply not enough time for all, or even most, soil properties to reach quasi-equilibrium. For instance, the soils of glacial and periglacial areas of the Russsian Plain are of Holocenic age, i.e. they are about 10,000 years old. At the same time, even if the general conditions of climate and topography remained constant for a sufficiently long period of time, the denudation and eolian transportation of substance constantly supplied new portions of immature material to be involved in the soil-forming process. Even during the Holocene, however, natural-climatic conditions markedly changed.

Thus, during the Holocene, the processes of self-development of soils were to a certain extent maintained in the process of soil formation and there occurred the processes of "induced" development of soils that followed the changes in the natural-climatic conditions. The change of soils which follows the changes in the external factors of the environment is called the evolution of soils.

The conditions required for a "pure" monogenetic development of soils rarely exist. The polygenetic soils which survived several (two and more) periods of monogenetic development are usually in non-tropical areas.

SOIL IN A NATURAL ECOSYSTEM

The condition above makes it possible to consider soil as a very complicated component of ecosystems, as an open subsystem requiring different approaches and methods of investigation (Rode 1971, Jaalon 1970).

On the one hand, a mature soil (its composition and organization) in "to-day's" ecosystem is the product of activities of not only "to-day's" ecosystem but of all the preceeding ecosystems which existed on the given territory since the earliest appearance of vegetation, i.e. from the beginning of soil formation. Mature soil observed in "to-day's" ecosystem had to inevitably survive all the stages of monogenetic development and long natural evolution on a given site, unless soil outwash or burying occurred (Polynov 1930, Gerasimov and Glazovskaya 1960, Kovda 1973). Therefore, a mature soil profile and its stable conservative properties must be considered the "memory" of both self-development and evolution of landscapes (Targulian et al. 1974, Armand 1975, Sokolov and Targulian 1976). The processes of the last monogenetic stage can completely, or partially, eradicate the features of the former processes or be superimposed on them.

On the other hand, a mature soil profile is not only a "preserved memory of the former processes but also the most significant material basis, the dynamic "component" which directly takes part in the functioning of today's ecosystem. In this sense, it is

ossible to speak about "life" of a mature soil or about its ynamics.

The realization that soil is a long-formed product (memory of elf-development and evolution) and a "living" continuously unctioning component of today's ecosystems both determine the eneral approach to the investigation of soils at the biosphere tations.

The investigations of soil statics (composition, profile rganization) are significant as the basis for memory deciphering nd for the understanding of contemporary processes, even though hey cannot explain completely today's work of an ecosystem and he role of soil in this work. Similarly, the investigation of he current life (i.e. modern dynamics) of a mature soil in the cosystem does not fully explain its genesis, i.e. its path of evelopment in time, starting from time-zero and up to the present, nd the mechanisms which have brought about its present condition.

Each of these two directions of investigation has its theory nd methods. And it is only by combining the results of investi- ations in these two directions that one can obtain full and ersatile knowledge about soils at the biospheric stations which an be regarded as standards for observing nature and its anthro- ogenic changes.

HE INVESTIGATION OF STABLE, CONSERVATIVE PROPERTIES OF SOIL ND THE SOIL MANTLE

The tasks of such investigation are diverse. They involve: a) description of the object, i.e. the cognition of morphology, ubstance composition, and organization of the solid phase of a oil body; it is obvious that this work will demand application of he majority of contemporary methods of investigating territory nd substance; (b) determination of the dependence of soil com- osition and organization on environmental factors (both the outer nes, with respect to the ecosystem, and the inner ones); (c) laboration of the soil genesis concept. This complete genetic oncept should be based on the understanding that mature soil esults not simply from the interaction of factors and mechanism f soil formation, but also from a certain historic (temporal) uccession of these interactions. Such a concept is based on a eries of particular empirical hypotheses concerning the essence, et, spatial distribution, and temporal succession of the ele- entary soil-forming processes (ESP). This task can be considered he most significant in the study of soil- "memory".

A promising approach for the study of stable, conservative soil roperties and mantle is one based on the concept of a hierarchy f organizational levels of soil body components (table 1). nvestigation at each level permits us to disclose its character- stics and internal regularities (Rozanov 1975).

Table 1--Basic levels of soil organization and methods of research

Level of organization	Method of research
1. Pedosphere	Presently not yet under investigation at Biosphere Reserves.
2. Soil mantle	Surface cartographical, aerial methods of investigating the structure of the soil mantle. Terrain - geochemical methods of studying geochemical soil conjugates.
3. Soil profile	Field macro-, meso-morphology; morphometrics; field physical and chemcial techniques; profile experiments as a whole.
4. Soil horizon	Macro-, meso-, micro-morphology (optical and scanning microscopy), material composition and characteristics of the general mass of the horizon (granulometrics; chemistry; bio- and physio-chemistry; mineralogy, etc.).
5. Soil aggregate	Mezo- and micro-morphology (optical and scanning microscopy); sample analysis; material composition and characteristics of the ped parts; micro-probe analysis.
6. Crystal, olecule	X-ray, X-S; spectrometrics; electron microscopy; micro-probe, chemical and other analyses of the composition and transformation of minerals, amorphous organo-mineral and organic substances at the crystal and molecular levels.
7. Atom-Ion	Chemistry and radio-chemistry of isotopes in the soil; sprectrometric and chemical methods of studying ion exchange and ion migration in the soil.

Investigations of organizational levels of soil bodies is not just a "privilege" of the first research direction soil memory studies; they can also be carried out during current soil life studies. For the first research direction, the most important studies appear to be investigations (without omitting levels) of the composition and organization of soil, as a basis for genetic hypotheses, related to "processes" and "time". Although the study of stable, conservative soil properties and the formation of genetic concepts are important, it still does not answer these questions: (1) what in the soil body observed today exists as a product of present processes and what of past, that have already ceased or

are extraordinarily slow; (2) are presently observed soils mature and "working" in a dynamic equilibrium, or do directional processes continue to function within them; (3) what are the nature and quantitative characteristics of current processes.

Only after these questions have been answered, can we reveal the tendency of current soil development in natural ecosystems and forecast the future. These tasks are being resolved by studying the current life (dynamics) of soils and the soil mantle.

THE INVESTIGATION OF THE CURRENT "LIFE" (MODERN DYNAMICS) OF SOIL AND ITS FUNCTIONING IN TODAY'S ECOSYSTEM

From all of the combined processes of soil formation, it is possible to single out the following groups:

1. The cyclic processes. They are characterized by a periodic return of the system to one and the same or to a very close status. The duration of periods remains constant. This is associated with the fact that the duration of cycles and their superimposition over each other (diurnal, annual, etc.) are determined primarily by general planetary factors.

2. The arbitrary or quasi-periodic processes. They are characterized by a periodic return of the system to an analogous status in time intervals of arbitrary duration. Obviously, it is possible to regard as arbitrary some reversible changes of forest soils (humus content, thickness of litter) depending on which part of the tree crown (near to the stem, crown edge or "window" between the trees) at a given moment is over the profile under investigation.

3. The trend (directed processes). This represents those changes, during which the system status is not repeated in any time scale. In a humid climate, the removal of dissolved compounds outside the soil and ecosystem is related to such processes. The direction of the process is preserved for long intervals of time (hundreds and thousands of years), and very short periods (one day).

The groups of processes usually occur in soils and ecosystems in complex combinations. Frequently, the cyclic and directed processes combine. Such a "hybrid" process consists of a series of cycles which are not completely closed and, therefore, at the end of each cycle, the system status changes by a small residual value. The accumulation of these values gives rise to the directed change in the soil properties trend. To these processes belong: humus accumulation in soils, differentiation of the majority of elements in the soil profile, leaching out or salinization in semi-arid conditions, etc. The arbitrary (quasi-periodic) processes superimpose in natural conditions the first two types and their combinations. When studying the cyclic and quasi-periodic processes, it is important to bear in mind that both the direct and inverse phases of these processes can be: (a) not identical in their nature (absorption of short-wave and emission of long-wave radiation by soil); (b) separated in time and space (descending chemical migration and ascending biogenic migration of elements); (c) different in rates (supply and decomposition of litter-fall).

THE CHARACTERISTIC TIME

Each process can be related to a characteristic time (C.T.) (Armand and Targulain 1974). By the C.T. we understand: (a) duration of the period for the cyclic processes; (b) the average duration of the period for the quasi-periodic processes; and (c) time needed by the system for the restoration of the quasi-equilibrium disturbed by the outer influences - for the trend processes. Every component of an ecosystem, considered from this viewpoint, is represented by a complex of systems with different C.T. Moreover, the changes of every variable characterizing the states of soil components can be determined by a broad spectrum of C.T. Apparently, C.T.'s which correspond to the maximum amplitudes of changes should be regarded as the main ones. For such properties as moisture content of soils, pH, and others, the values of C.T. will be of the order of 10° - 10^{-2} expressed in days, seasons, groups of years; for the contents of humus and clay they will amount to 10^{2} - 10^{3}, i.e. to hundreds and thousands of years and for mineralogical profile to - 10^{5}, i.e. to tens of thousands of years.

When investigating the dynamics of the current life of soil, one should also take into consideration the hierarchy of characteristic times of the processes occurring in soil. Not infrequently the C.T. of processes is determined by the phase states of substances in which these processes occur. The processes occur most rapidly in the gas phase, more slowly in the liquid phase and on the interface between phases, and most slowly within the solid phase.

In order to study its present life, it becomes particularly important to view soil as a unique link in the natural ecosystem, inextricably tied, to all other links. To qualify this, we propose that each group of soil observations be related to observation on other components of the ecosystem. In table 2 this proposal is introduced in columns 5 and 6 at a very preliminary level.

Table 2 permits us to divide the approaches for studying soil and the natural ecosystem as a whole into two groups: direct study of regimens for "fast" processes and indirect study of "slow" processes via the results of those processes. This proposed division of the concepts "life" and "memory" (stasis and dynamics), as related to soil, are entirely conditional. Real soil is an unbreakable chain of interrelated processes, ranging from the incredibly "fast" to the very "slow". An operational division of processes into two groups can, however, be set up for those unfinished processes. Those processes which afford direct observations of functions can be ascribed to the soil's "life", all others to it's "memory". Further study of soil regimens should permit us to separate present "directional" process from those which have attained dynamic balance or have either culminated or become exceptionally slow.

SPATIAL VARIABILITY OF PROPERTIES IN A NATURAL ECOSYSTEM

Practical research on the temporary changeability of soils encounters considerable complications related to the spatial

Table 2--Characteristic times of several biogeocenological processes and their study

T	Atmosphere	Live organisms	Soil	Studied characteristics		Techniques
				Non-soil	Soil	
	2	3	4	5	6	7
5	Climatic fluctuations in the pleistocene		Formation of mineralogically, chemically & morphologically differentiated soil profile	Macrotopography, geology of fundamental & quaternary rock	Morphology, content & organization of the soil's hard phase	Paleographical methods; comparative geography; comparative soil horizon analysis
4	Same in the Holocene			Climate & vegetation history		
3	Same in the historical period		Formation of the humus profile	Mesotopography, geology of quaternary deposits		
2	90-yr. Climatic cycle	Formation of forest biocenoses	Biological soil cycles; quasi-cycles	Forest edificator composition artifacts	Soil horizon thickness, reserves of organic matter & ash elements	Constant observation
1	Solar cycle	Formation of grass biocenoses and large animal populations	Salt profile. Profile of exchange cations	Phyto- and Zoocenosis composition	Balance of organic matter & ash elements. Artifacts. Filtration capacity. Transposition of the hard phase	
0	Meteorological cycle	Formation of rodents, insects and others	Formation of a profile of easily dissolved matter; pH, OVP, etc.	Balance of moisture, heat, biomass. Activity of burrowing animals. Exogenous substances	Annual balance of "litter", roots. Composition of soil solutions. Content of various chemical elements	Constant observation
-1			Hydrological & temperature soil profiles	Precipitation, air temperature, snow cover, phenophases of plants and animals, drainage	Ground water levels, humidity, frost; ground temp. to 1 meter. Composition of soil, air, pH, EH, pF.	
-2 ys	Daily meteorological cycle	Daily biocycles		Air temperature, radiation, precipitation, transpiration	Temp. and humidity at depth of 30-40 cm, soil respiration	

variablity of properties and processes in a natural ecosystem's soil mantle. Spatial changeability of soils is brought about, on one hand, by past "inheritance", (by heterogeneity of soil "memory") and, on the other, by present spatial differentiations of a natural ecosystem's components.

We believe that the particular features of spatial variation in soil properties are fairly stable and characteristic of each "quasi-equiponderant" natural ecosystem. In this instance, research into soil heterogeneity becomes a goal in itself. The resolution of this goal has value in several respects: first of all, knowledge of spatial variabiltiy has significance for the selection of a research methodology; it permits us to define the requirements of regimen observation, in order to "uncover" real internal regularitie There is, however, still another more important substantive value in studying soil variability in various places. It is apparent that any instantaneous section of various properties of the soil of a given natural ecosystem carries information not only about its "memory", but also about the "present" life of the soil. By comparing the spatial variation of soil properties with the observed spatial structure of an ecosystem (i.e. the distribution of trees, microtopographical elements, etc.), one can evaluate to what extent individual properties reflect "memory" and to what extent they appear to be the result of contemporary processes. Subsequently, analysis of spatial variability of an ecosystem's soils aids in separating "today" from the past, in regards to both processes and masses or soil thicknesses caught up by these processes.

One of the most promising methods of solving this fairly complex problem may be the theory of casual functions, which is used to disclose the frequency structure of spatial variation of properties. This permits us to carry out a concerted search for those factors responsible for the instantaneous picture of property variation. Knowledge concerning genesis, current life, and spatial variability of natural ecosystem soils is necessary in order to understand the structure and functional operations of standard "reference" natural ecosystems of the world's biosphere reserves. Concurrently, we acquire inital information for monitoring and the development of dynamic forecasting models for natural ecosystems, subject to anthropogenic "pressure".

The program of direct observations of soils at the biosphere stations is based on the above-stated theoretical analysis and embraces the following four large groups of investigations:

I. Investigation of the soil mantle of the biosphere stations and the solid phase of soil profiles as the most stable characterisitics composing the background for regime observations.

II. Regime observations of the processes of substance and energy exchange of soil with the atmosphere, waters and vegetation.

III. Regime observation of the processes of substance transformation and migration within soil.

IV. Regime observations of the processes of horizontal redistribu of substance in the soil mantle (landscape-geochemical investigatio

The first group of investigation includes: (a) detailed mapping of the soil mantle with the use of surface and distance (aerocosmic) methods; (b) investigation of the substance composition of soil in accordance with soil horizons. This most traditional method of investigation provides the data on the chemical and mineralogical composition as well as particle size distribution of the soil. The results of these investigations serve as a "reference point" and background for observing the anthropogenic changes of soils.

The second and third groups of investigations, which are carried out in the representative "points" of biosphere stations, include the study of the following regimes and balances characterizing the modern dynamics of soil and its relationship with the other components of the ecosystem (atmosphere, vegetation, surface and ground waters, parent rocks):

1. The temperature regime of soils.
2. The heat regime and balance in soil.
3. The water regime and balance in soil.
4. The supply of dissolved substances to soil: (a) by precipitation; (b) by surface waters; (c) by ground waters (regimes).
5. The migration of dissolved substances within soil (regimes).
6. The outflow of dissolved substances from soil: (a) with surface waters; (b) with the lateral intrasoil flow; and (c) with the vertical intrasoil flow.
7. The gas regime of soil (CO_2, O_2, etc.).
8. The regimes of colloidal components of soil (composition and content of exchangeable cations, acidity).
9. The regimes of aggregate and microaggregate status of soil.
10. The regime of redox potential.
11. The regime of the contents of trace elements and heavy metals in soil.
12. The regimes of the contents of pesticides, insecto-fungicides, and other chemicals in soil.
13. The regime of the content of radioactive substances.
14. The regimes of the contents and compositon of salts and carbonates in soil.
15. The regimes of "mobile", i.e. extractable by various solvents, forms of different elements (N, P, K, trace elements, heavy metals, Si, Al, Fe, etc.).
16. The regime and balance of soil organic substance (soil humus and its separate fractions).
17. The regime and balance of organic substance in the biological cycle of the ecosystem (litter-fall, litter, etc.).
18. The regimes and balances of C, N, and ash elements in the biological cycle.
19. The regimes of the quantity and composition of soil microflora and soil fauna.

At present, the knowledge of the regimes stated in points 4, 5, 6, 11, 12, 13, 14, 15, 16, 17, 18, and 19 is the most significant for the study of the direct anthropogenic influence on the ecosystems.

The fourth group of investigations includes a series of observations to be conducted on the typical spatial combinations of soils (soil catenas, geochemical landscapes) in the biosphere stations.

These observations make it possible to study the redistribution of substances over the area which in different cases can result in self-purification (eluvial position) or in greater pollution of soils (hydrogenic-accumulative positions). The following investigations belong to this group:

1. The regime and balance of the surface flow of water, chemicall dissolved susbstances and solid particles.
2. The same for the lateral intrasoil flow.
3. The transportation of substances by ground waters.
4. The regime and balance of eolian transporation of solid substances on the surface of soil.
5. The forms of migration and accumulation of substances (primarily the polluting ones) in the soil mantle.
6. The processes of transformation (sorption, precipitation, activation and inactivation) of polluting substances in soils.

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Primary Productivity Studies in Biosphere Reserves (Methods and Initial Results)

by

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INTRODUCTION

Methods of studying biological productivity (primary production, annual litterfall, stocks of standing crop, debris, and total organic matter) have been developed for specific tasks and types of ecosystems by many investigators.

Special attention was drawn to these methods during the International Biosphere Program (IBP), which were presented in a number of manuals (Remezov et al. 1963, Programme-minimum 1968, Rodin et al. 1969), and used by Soviet investigators in the IBP framework. These methods are based on the following principles: selection of a representative area (to cover a zone, a type of vegetation, biogeocenosis-ecosystem, microcenosis or parcella), establishment of registration plots, determination of standing crop parameters, and measurement of primary production of litterfall, litter, litter decomposition, etc., in different seasons. It is essential to conduct the experiment in a way yielding a full inventory of real production in a unit of time (10 days, a month, a year). The daily production is arrived at by estimation since direct determination is impractical in field conditions. The method suggested by A. A. Titlyanova (1971, 1974) is very promising. It is based on a systemic approach. "Blocks" are singled out within the grass biogeocenosis (standing crop, debris, litter, roots) and "flows" determined (increase in standing crop, arrival of debris from the standing crop block to the block of debris, arrival of litter from the block of debris to the block of litter, etc.). A system of balanced equations has been worked out to describe the mass of organic matter in the period chosen for investigation. Though the author's task is more ambitious--the study of the biological circulation in the biogeocenosis--the determination of primary production using the suggested methods can be achieved with greater accuracy. An essential factor is that A. A. Titlyanova's method takes into account full produciton of the subsurface sphere of the biogeocenosis as well. The wide application of A. A. Titlyanova's method thus far is "in statu nascendi," though there are publications about its application to the study of steppe associations (Titlyanova and Bazilevich 1975b, Bazilevich, editor 1975).

Now we shall review the studies concerning biosphere reserve areas.

FRANZ JOSEF LAND

Primary production was studied by V. D. Aleksandrova in 1966 (fig. 1). She investigated a polar desert and used her own methods (1958) of identifying living and dead phytomass; in 1970 she compared these findings against the standing crop values in other northern subzones (g/m^2, air-dry weight):

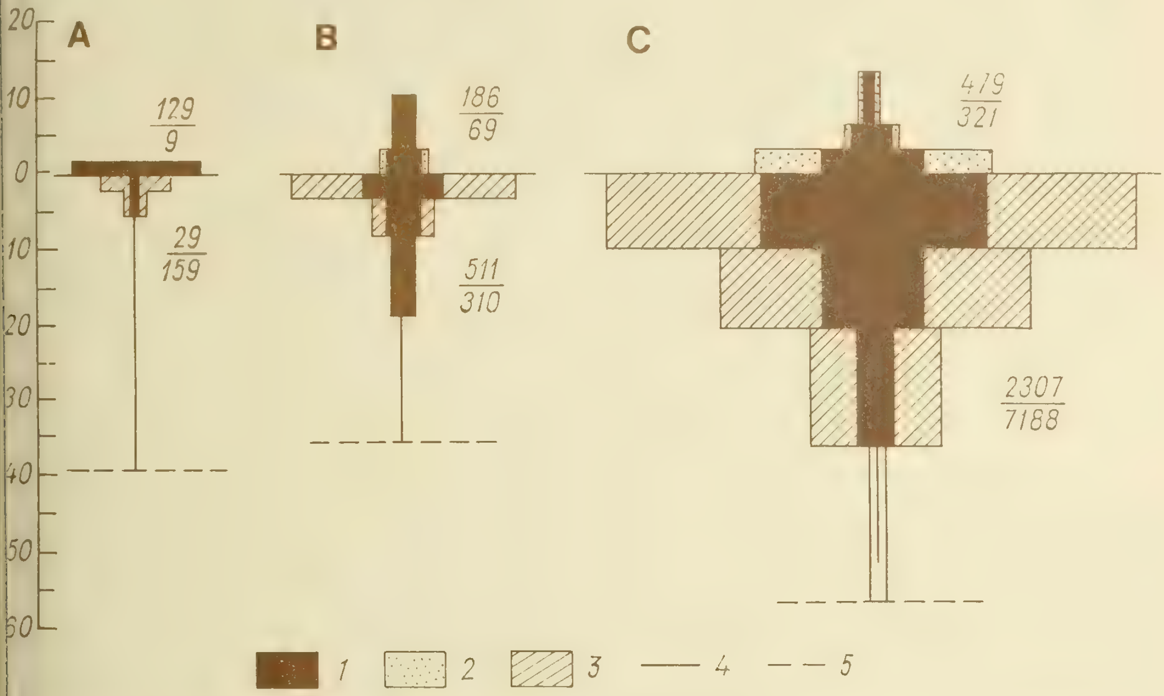

Figure 1.—Structure of vegetative mass in tundra and polar desert associations (according to Aleksandrova 1970). A—Polar Desert (Franz Josef Land); B—Arctic Tundra (Liakhovskii Island); C—Southern Tundra (Koryakskaya Land). 1—live plant mass; 2—dead surface phytomass; 3—dead subsurface phytomass; 4—soil surface; 5—frost level. Numerator values = live phytomass. Denominator values = dead mass, g/m².

Phytomass	Polar desert. Franz Josef Land	Arctic tundra. New Siberain Islands	South tundra. Koryak Land	South tundra. East-European forest-tundra
Living plant parts	158	696	2 786	5 878
including: surface	129	185	479	2 162
subsurface	29	511	2 307	3 716
Dead plant parts	161	379	8 309	11 324
including: surface	9	69	521	24
subsurface	152	310	7 788	11 300
Total organic matter	319	1 075	11 095	17 200

An examination of the figures above reveals an important regula
the surface part prevails (78%) in the standing crop of polar dese
(Franz Josef Land), whereas in the arctic and southern tundras the
surface part makes up 38 and 17%, respectively.

The differences in terms of the absolute volume of all paramete
are quite significant - by the order of one or two.

For instance - total organic matter:

Polar desert	319 g/m^2	1
Arctic desert	1 075 g/m^2	4
Southern tundra	11 095 g/m^2	35

Flowering plants (angiospermous) in the polar desert standing cr
structure comprise 23%; moss and lichen make up 76%. In the Arctic and southern tundras the flowering plants account for 83 and 91%, respectively, while the balance is mosses and lichens.

The annual primary production was identified only in a few sites of the Arctic:

	g/m^2	t/ha
Northern patchy tundra (Western Taimyr)	37-42	0.37-0.42
Yernik moss tundra (Harp Station)	35-40	0.35-0.42
Shrub-sedge-moss tundras (mid reaches of Pyasina River)	70	0.70
Mountainous tundra (different associations) (Kola Peninsula)	63-321	0.63-3.21
Yernik lichen-moss tundra (Komi, Vorkuta District)	442	4.42
Arctic tundra (estimated data, Rodin and Bazilevich 1965)	-	1.0
Southern tundra (ibid)	-	2.38

The range of fluctuation of annual production values is consider
and available data are insufficient. It might be noted that annual
production in northern and southern tundra subzones differs twice
and even three times, while the tundras of the forest tundra zone
differ by one order.

The comparison of available Soviet data against the data of othe
authors shows considerable agreement.

	t/ha
Barrow, Alaska, 71°C N.lat. (Bliss 1962)	0.5-2.24
Umiat, Alaska, 69° N.lat. (Bliss 1956)	0.6
Gratangen, Norway, 68°39" N.lat. (ibid)	0.5
Abisko, Sweden, 68° N.lat. (Pearsall a.Newbould 1957)	2.42
Mountain tundra, USA (Bliss 1956)	0.2-2.08

The data most likely have been obtained by different techniques, and the determinations were made in different seasons of the year, but the results are in the same order of value.

The most important factor which determines the value of primary production is the intensity of photosynthesis. In high latitudes of the Arctic the study of potential intensity of photosynthesis (PPI) was conducted at Vrangel Island by T. B. Gerasimenko (1973) and by Voznesensky et al. 1965 (by the radiometric method). It has been found that at Vrangel Island photosynthesis takes place in a wide temperature range--from -3° to +45°.

Plants were found with high or low photosynthetic intensity in mg CO_2/g dryweight/hour:

High assimilating		Low assimilating	
Caltha arctica	182	*Carex lugens*	66
Rhodiola borealis	132	*Luzula nivalis*	48
Rumex arcticus	121	*Dryas punctata*	33

The PPI range in plants at Vrangel Island is similar to that in the plants at Khibiny and Pamir Mountains (Zalensky 1963).

In the circumstances of the long polar day, plants go on assimilating CO_2 round the clock. The highest PPI values are noted in morning and midday hours. At midnight the assimilation rate may be 5% of the maximum midday PPI.

Large-scale studies for evaluation of forage vegetation in the North have been carried out in the U.S.S.R. V. N. Andreyev (1971) worked out a method of determining green (vegetating) parts of plants which are used for forage (leaves and shoots of grasses and semishrubs). The application of this method combines aerial and surface observations. Tables have been compiled where the wanted value in terms of tons of air-dry mass per hectare is identified on the basis of singling out the contours of definite units of vegetation. From medium-scale geobotanical charts, it is possible to compile a chart of distribution of the stocks of forage resources. More than 60 geobotanists collected a tremendous volume of material using the same method (300,000 points of visual determination and 0,000 hay cuttings). Chamber processing yielded quantitative evaluations of the standing crop and annual production for six zones and subzones of the east European north (fig. 2, 3, 4).

The following regularities have been found: standing crop diminishes from the northern forest zone boundary to the polar ocean coast at a rate of 25 times (from about 12 to 0.5 t/ha), while the annual production dwindles 4.5-fold (from 1.2 to 0.27 t/ha). The volume of annually renewed above-surface standing crop increases gradually from 10% in the subzone of light taiga to 65% in the Arctic semidesert. In addition, other authors worked in tundras

(Abisco, Cape Barrow, Devon Island, etc.) and in mountain (alpine) tundras on high latitude Arctic regions outside the U.S.S.R. Considerable difficulties are encountered in comparing Russian and foreign data: (1) foreign scientists (several critical remarks hav to be made here) did not define acurately the type of the biogeocenosis (the ecosystem) and confined themselves to measuring only the production of flowering plants (and, at times, only the sporous plants - mosses and lichens); and (2) annual production was interpre

Figure 2.—Surface phytomass by subzone of the eastern European north—T/ha (metric ton per hectare), air dry weight (according to Andreev 1966). A—Arctic semi-desert; B—Arctic tundra; C—Northern tundra; D—Southern tundra; E—Sparse forest tundra; F—Sparse forest.

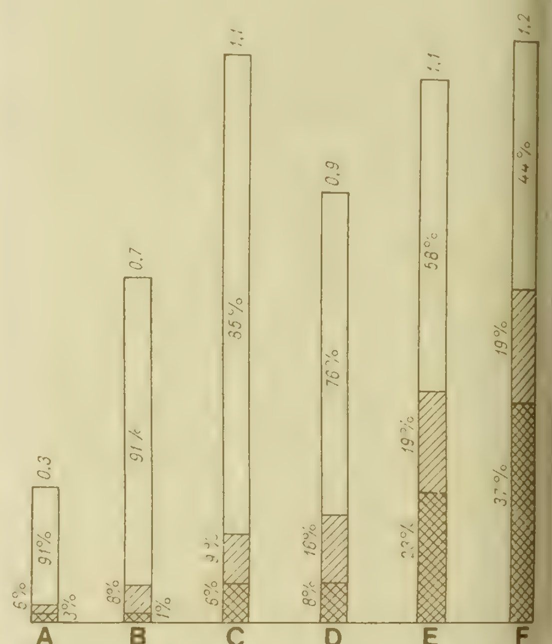

Figure 3.—Annual increase of plant surfac parts and its distribution among species (phytomass in subzones of the easter European north—T/ha, air-dry weigh (according to Andreev 1966). 1—annu green organs; 2—perennial green organ including moss and lichens; 3—woo A—Arctic semi-desert; B—Arctic tundr C—Northern tundra; D—Southern tundr E—Sparse forest tundra; F—Sparse fores

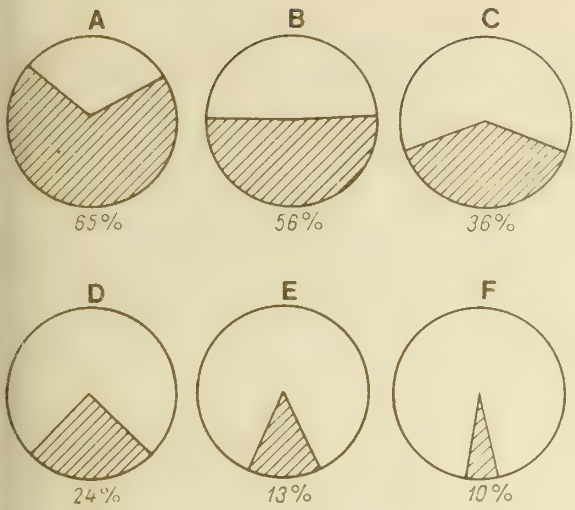

Figure 4.—Annually renewed portion of surface phytomass by subzones of the eastern European north (in %, according to Andreev 1966). A—Arctic semi-desert; B—Arctic tundra; C—Northern tundra: D—Southern tundra; E—Sparse forest tundra; F—Sparse forest.

as the maximum phytomass at the period of its greatest development, which is naturally less than the actual annual production. We shall, nevertheless, present some of the relevant data.

The annual primary production of flowering plants in 1971, g/m^2 (absolute dry weight) on Devon Island, Canada (close to 75° N.lat.) and in Gardangevidde, Norway (60° N.lat.) are as follows:

Tundra types	Surface	Sub-surface	Total g/m^2	Total t/ha
Spotty northern tundra (Muc 1973)	27.4	70.1	97.5	0.97
Hillocky sedge tundra (Muc)	47.0	191.4	238.4	2.4
Humid sedge meadow (tundra) (Muc)	46.4	160.1	206.5	2.1
Coastal semibrush-sedge tundra (Svoboda 1973)	15.5	4.8	20.3	0.20
Pebbly moss-semibrush tundra (42% rocks) (Bliss and Kerik 1973)	no data	no data	44.1	0.44
Mountainous lichen tundra (Wielqolaski and Kjelvik 1973)	151	111	262.0	2.6

As we compare these latest data obtained in the IBP program against the previously mentioned Soviet and even earlier foreign data (prior to IBP), one can see that they agree with both.

YAKUTSK (CENTRAL TAIGA)

The Yakut stationary establishment, the Institute of Forest and Timber of the Siberian Branch of the U.S.S.R. Academy of Sciences has been in operation since 1955, 28 km north of Yakutsk. The head of the establishment is L. K. Pozdnyakov. Since 1960, another 15 stations were established in all taiga zones and in basins of a number of rivers. I. P. Scherbakov and V. N. Andreyev (1969) reviewed the study and the prospect of utilization of Yakut vegetation. The stations carried out diverse studies of forests on biogeocenological principles. The parameters were determined by establishing permanent study areas. Use was made of conventional inventory using tree models (the technique is described in detail by Pozdnyakov et al 1969).

As a result of many years of investigation, vast data has been accumulated describing the phytomass of trees. The relevant information has been analyzed, and correlation dependencies have been found between the main valuation indices of tree species and the parameters of individual fractions of the phytomass. Seventeen reference tables have been compiled on their basis, including: crown weight; needle weight; the content of dry substance in wood, leaves and needles of trees, shrubs, and grasses; the weight of roots depending on the weight of the trunk; the weight of generative organs of trees, shrubs and grasses, etc.).

The tables take into account the age of species and their geographical location. Main attention was given to pine forests owing to the increased demand for pine timber and to the fact that pine woods are confined to the valley of rafting rivers.

The following information describes the standing crop of pine forests in central taiga (Pozdnyakov et al. 1969), in t/ha.

Age	Standing			Underbrush regrowth	Surface cover	Surface phytomass	Roots	Total phytomass
	Timber stock m^3	Trunk and crown	Needles and leaves					
100	115	62.3	3.1	1.79	4.29	71.5	13.7	85.2
140	171	90.9	3.4	3.91	3.21	101.4	23.7	125.1
180	186	99.3	4.0	1.31	3.82	108.4	25.4	133.8

Larch forests prevail on vast expanses of Yakutia. Its productivity is noticeably higher than that of pine forests in the same zone of the central taiga (Pozdnyakov 1975). Thus, the standing crop of larch forests in Central Yakutia is characterized by the following indices (Pozdnyakov et al. 1969) (t/ha).

Age	Standing Timber stock m^3	Trunk and crown	Needles and leaves	Under-brush, re-growth	Surface cover	Above surface phytomass
50	110	53.4	2.2	0.01	0.08	55.7
90	230	140.0	3.4	0.10	0.29	143.7
130	175	107.2	2.1	0.27	1.06	110.6
170	190	117.5	2.0	0.30	1.52	121.3
200	186	118.4	2.1	1.31	2.57	124.4

This book (Pozdnyakov et al. 1969) presents much more detailed information on forest productivity of the entire Yakutiya and Central Siberia by species, zones and districts. Further analysis of the available and future data will make it possible to compile mass tables for a number of biometric indicators similar to the valuation tables available to the forest investigators and practitioners. The application of the tables suggested by Pozdnyakov et al. 1969, helps to considerably reduce empirical measurements and labor-consuming operations related to cutting of model trees, establishment of numerous plots, etc. As a rule, the predictive accuracy of calculating the appropriate values in keeping with these tables within ±10%, which is adequate for practical and for many theoretical objectives.

L. K. Pozdnyakov (1970) notes that there are two interrelated approaches to the study of forest biological productivity (just as of other types of vegetation). The first is the study of biological circulation of matter and the geochemical role of the forest; the second is the study of the forest phytomass from the point of view of identifying the ways of its utilization as timber or as raw material for industry (pulp and paper, chemical, food, and other industries), i.e., the study of its economic productivity.

LAKE BAIKAL

The primary production of Lake Baikal was studied by A. I. Mescheryakova (1975) by the flask technique (Vinberg 1934); this technique provides for calculating the volume of C_{org} in g/m^2. Studies have shown considerable fluctuation of this value from season to season (spring - 50.2, summer - 41.4, autumn - 9.1, winter - 23.7 C_{org}/m^2); from year to year (1966 - 75.1; 1967 - 127.9; 1968 - 187.4 $C_{org}g/m^2$ per year); and in different parts of Lake Baikal (southern Baikal - 131.1; northern Baikal - 119.0; the Barguzin Gulf - 80.2 $C_{org}g/m^2$ per year). Overall these figures vary from 2-fold to 2.2-fold.

On the average, 0.05% of the total solar radiation on the lake surface is utilized annually in southern Baikal districts. The greatest efficiency occurs in August (0.21%), the least in November (0.0002%). Total primary production of Lake Baikal as a whole, comprises 1,000,500 tons C_{org} or 80,010,000 tons of raw algal mass.

Detailed dendrochronological studies have been carried out for many years in Lake Baikal area (Galaziy 1972). This is another method of studying primary production - dendrochronological - was also applied. The analysis included larch and cedar trees, 300-400 years old. Cyclic changes in the growth of timber were found with average duration of 65-70 years beginning with the 13th century; it may be suggested that this value is a multiple of the 33-35-year Brikner cycle of solar activity.

In the climatic aspect, these cycles demonstrate themselves in increased humidity of the atmosphere and an increased water level in Baikal. In recent years we are registering an increase in the annual timber growth rate in Lake Baikal areas.

The possibilities of the dendrochronological technique have by no means been exhausted. Broader and deeper studies of primary production of plants and plant cover will, without fail, lead to new correlations which should make it possible to forecast biological production 3-5 decades in advance (as well as the atmospheric humidity, general thermo-availability, river water capacity, snow cover capacity, etc.). This is of great importance for advance, long-term economic planning (Galaziy 1957).

KURSK

The annual production at the Kursk station was investigated by empirical (cuttings) and estimate techniques based on model trees using growth tables. Annual production of the surface mass in tons per hectare has been determined (Utekhin 1972):

Open steppe areas	2.9 - 4.5
Forest associations	5.3 - 7.1
Barley fields	3.6 - 10.0

Fluctuation of production within the indicated range depends upon humidity, temperature, and the radiation balance. Thus, the stock of standing crop in a meadow steppe on a watershed, at the time of the maximum mowing (after Utekhin et al. 1975) in tons per hectare, was

1969	1970	1971	1972
3.2	2.7	3.1	3.8

Naturally, the annual production varies in the same range. Total annual production of the uncut meadow stock was determined in 1972 after Titlyanova's method (1971). It proved to be:

Above surface phytomass		4.2 t/ha
Subsurface organs		8.4 t/ha
	Total	12.6 t/ha

Approximate estimates of complete primary biological production (with consideration for the subsurface mass) indicated that the production of farm crops, even when highly developed farming methods are used, does not exceed total production of natural vegetation. This can be seen clearly from the following data on the production of the surface phytomass calculated by V. D. Utekhin (Gerasimov 1966):

Item	Virgin land	Virgin land with fertilizer	Sowing at experimental station					
			Spring wheat			Barley		
			Grain	Straw	Total	Grain	Straw	Total
Phytomass, t/ha	6.60	9.24	1.61	4.89	6.50	2.27	2.45	4.72
Fodder units/ha	3 300	4 620	2 010	1 090	3 100	2 840	880	3 720

Thus, natural biogeocenoses in the steppe utilize solar radiation and precipitation with greater efficiency for primary production than crops cultivated by highly developed farming techniques at an experimental station. I. P. Gerasimov (1966) believes that this is due to a more complex structure of the virgin land biogeocenosis in the surface and subsurface sphere, which makes possible fuller use of environmental resources (temperature, humidity, soil fertility and other factors). The experiment with fertilized virgin land exceeded the harvest of wheat 1.5-fold and the harvest of barley almost 2-fold. If medium grade farming methods are used on collective-farm soils, the harvest most likely would be one half or one third of that grown in a virgin steppe. Consequently, the potentialities of the cultivated vegetation are not being entirely utilized.

REPETEK

The Repetek Reserve was established in 1912. The studies covered a large program and there are three volumes of the proceedings of the Reserve, and also numerous publications registered in professional bibliographies (Klyushkin et al. 1955, Vejisov and Ishankuliyev 1972). Many aspects of the biosphere have been studied at Repetek and some of them are classical (Dubyansky 1928, Orlov 1928 and other publication of this author, one of the first investigators and directors of the station, Petrov 1933, 1935; Radkevich 1934, Blagoveschensky 1942, Znamensky 1949, and many others). Only a few works, however, were devoted to separate parameters of primary production; for instance, the stock and growth of fuel timber

(Leontiev 1954) and the stock and production of forage mass (Togyz 1967). Planned studies of primary production commenced in 1965 wi the beginning of the IBP period.

The study of photosynthesis--the physiological and ecological basis of primary production--were carried out by conductometric an radiometric techniques (Voznesensky et al. 1965). It has been fou that CO_2 assimilation in most of the desert plants takes place throughout the light hours of the day during the vegetation season (Voznesensky, editor 1975). The following are the relevant data:

Species	Photsynthesis intensity, mg CO_2/gr dry weight per hour		Average photosynthesis productivity, mg CO_2/g dry weight per day	Optimum of observed photosynthesis, °C	Respirati intensity mg CO_2/g raw weigh per hour
	Observed average for vegetation season	Potential			
Ammodendron conollyi	7.6	71	110	22-35	1.2
[illegible] persicum	6.1	30	55	10-45	1.1
[illegible]	7.1	40	80	10-30	1.2
[illegible]	5.8	23	80	25	0.7
Ephedra strobilacea	2.3	30	30	5-20	-
Aristida karelinii	21.0	110	250	30-40	1.6
Carex physodes	14.0	65	205	17-30	-

The highest photosynthetic intensities in all plants take place in spring - the most favorable season in the desert. Particularly active are representatives of ephemers and ephemeroids. Low intensities of photosynthesis are characteristic of the species which vegetate for a long time. Plants of Karakumy deserts are capable of assimilating in a wide temperature range from -5° to 55°C. The optimal assimilation temperature for the majority of plants is 25°-30°C.

A remarkable feature of many desert plants is the wide range of optimum temperatures for photosynthesis; *Haloxylon persicum*, for instance, assimilates equally well in a range from 10° to 45°C. The lowest optimal temperature is characteristic for the evergreen *Ephedra strobilacea*, which allows this shrub to continue assimilation even in winter time (on warm days).

As for the daily amount of CO_2 assimilated (photosynthetic production), high capacity is demonstrated by trees and shrubs of long vegetation with a small value of productivity, and grassy plants which vegetate for a short time but have high productivity of photosynthesis. Therefore, considerable primary production of plants with a short vegetation cycle is achieved due to intensive photosynthesis. In plants which vegetate for a long time with low intensity of photosynthesis, however, it is due to the duration of the vegetation period. As a result, the different species of the Karakumy Desert assimilate annually approximately the same volume of CO_2 - close to 15 g CO_2/g per year. Magnitudes of leaf respiration in Karakumy plants are in the range of 0.3 to 1.6 mg/CO_2 per g dry weight per hr. The ceiling for critical respiratory temperature in hot desert plants exceeds values known for temperate zone species and is close to magnitudes for tropical plants. Calculation of the daily balance of substance has shown that in ephemerals respiratory efforts begin to exceed photosynthesis towards the end of their vegetation period; this may, perhaps, be the reason for their death at the beginning of summer.

On the whole, proceeding from the studies at Repetek and in other deserts, it may be concluded that the majority of warm desert plants have certain adaptations which allow them to complete the full development cycle.

Primary production of the associations in the Repetek Reserve has been studied in great detail. The stocks of phytomass of the tree - shrub tier and of the grass cover, as well as the annual production, annual offall, seed production, decomposition of the offall, etc., have been determined. An idea about the stock of above surface phytomass of the main biogeocenosis of the reserve is given by the data of Y. M. Miroshnichenko and R. Togyzaev (1972) (t/ha raw mass):

Biogeocenosis	Number of live plants per ha		Phytomass o[f] live plants t/ha
	Edificators	Other shrubs	
Haloxylon ammodendron - Suaeda lipskyi	512	81	67.9
Haloxylon ammodendron - Carex physodes	561	193	9.9
H. persicum - Carex physodes	160	48	5.3
H. persicum - Calligonum sp. sp.	146	226	2.9
Eremosparton flacidum - Aristida karelini	60	51	0.2

Thus, the phytomass volume in different biogeocenosis varies by 1 or 2 orders which is completely explained by the sum total of environmental resources in each case. A more detailed study was made of biogeocenoses of *Haloxylon ammodendron* - the most producti[ve] in the Repetek Reserve - in which the phytomass and the annual production in the above surface and subsurface sphere of all components-producents were determined (Rodin, editor 1975) (t/ha, air-dry weight):

Species	Phytomass	Annual production	Mortmass	Total organic matter
Haloxylon ammodendron - Carex physodes	26.9	7.5	3.4	30.3
H. ammodendron - Suaeda lipskyi	63.5	16.3	-	-

Thus, the annual primary production of biogeocenosis of *Haloxyl[on] ammodendron* is in the same order of values as the production of steppe vegetation. The main reason for this phenomenon is the hig[h] temperature resources, high solar radiation, the length of the vegetation period, and particularly, the successful adaptation to the extreme conditions of life in the desert not only of the edificators, but of all components of biogeocenoses capable of accumulating organic matter at both low and high temperatures. It is found in recent years that a noticeable share in the development o[f] primary production of biogeocenoses of *Haloxylon ammondendron* bel[ongs] to mosses and algae, which supply approximately 3% of the annual primary production. This is fully comparable to the volume of surface primary produciton created by grass cover plants. When th[e]

moss cover (*Tortula desertorum*) is very abundant, its annual production may reach 6-9 t/ha (Novichkova-Ivanova 1976).

An outstanding ability of desert associations is the development of vast and powerful root systems. They comprise 60-75% and 70-75%, respectively, of phytomass and annual production in the mentioned biogeocenoses, *Haloxylon ammodendron*. It should also be stressed that in these associations, a few species-edificators play an exceptional role; thus, in the biogeocenosis of *H. ammodendron* - *Carex physodes*, both species produce 83% annual production and even 89% of the volume of ash elements involved by them.

In conclusion of this brief review, the following comparisons of biosphere reserves in the U.S.S.R. are offered:

Territory and type of vegetation	Latitude, °N.lat	Precipitation, mm	Sum of temperatures (>5°C)	Phytomass, t/ha	Annual production t/ha	Production $g/m^2/day$
Franz Josef Land (Arctic tundra)	72°	500	1200	5.0	1.0	1.7

Territory and type of vegetation	Latitude, °N.lat	Precipitation, mm	Sum of temperatures (>5°C)	Phytomass, t/ha	Annual production t/ha	Production $g/m^2/day$
Yakutsk (middle taiga)	62°	192	1900	144.0	-	-
Baikal (lake)	53°	-	1600	-	1/ 187.4	0.9
Kursk (meadow steppe)	51°	687	2800	23.7	12.6	6.6
Repetek (desert)	38°	114	5600	26.9	7.5	4.0

1/ 187.4 is $C_{org} g/m^2$, not t/ha.

Thus, the biogeocenoses situated in such remote latitudes differ greatly in climatic conditions and, accumulated phytomass. The intensity of primary production, conventionally calculated for the number of days of the vegetation period in $g/m^2/day$, proved to be noticeably similar. It is natural that the highest intensity in the creation of primary produciton is found in the steppe where environmental conditions are particularly favorable.

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Research on the Higher Vertebrates in Biosphere Reserves

by

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The study of higher vertebrates, in the context of research at biosphere reserves, most likely should be oriented in the following way:

MONITORING THE STATE OF ZOOCENOSES OF REFERENCE ECOSYSTEMS

Monitoring the state of zoocenoses of reference ecosystems should guarantee continuous control of taxonomic and ecological structure of biocenoses and the state of their components. The observation should cover, at least, the size of the populations and the ecological-physiological state of the leading species of the main biological forms. Specific attention should be devoted to declining species. Monitoring animal population levels is a conventional aspect of research at natural reserves. This type of monitoring will probably not present special difficulties. It is more complicated to select the parameters for evaluating the ecological-physiological state of vertebrates. Probably resolution of this question will be facilitated by applying the method of morphological-physiological indicators suggested by S. S. Shvarts. The monitoring of the accumulation in the organisms of vertebrates of chemical substances--industrial waste and pesticides--and their migration along the alimentary chain is indispensable. It is likewise expedient to arrange monitoring of animal behavior and the development of synanthropisation.

The collected material should be published once every 3 to 5 years and circulated, on an exchange basis, to all biosphere reserves and to other concerned establishments. This would facilitate comprehensive global analysis of animal populations.

AUTECOLOGICAL STUDIES

It is natural that the preservation of zoocenoses in reference ecosystems, the study of their ecological structure and functioning just as the monitoring of their state, should have a fundamental autecological basis. Therefore, studies at biosphere reserves should include the distribution of individual species of mammals and birds, habitat peculiarities, phenology, migration, nutrition, breeding and mortality, age and sexual structure, behavior, seasonal and multi-year dynamics of the number of populations and

the influence of natural and anthropogenic habitat factors upon all these processes.

Zoologists face a great deal of work covering all the mentioned areas of research which will be conducted concurrently at all biosphere reserves. The latter circumstance taken together with the standardization of research methods will guarantee complete comparability of all findings. Therefore, it is necessary to determine the appropriate staff composition of research and scientific-supporting personnel at reserves, identify other scientific establishments in the light of their possible involvement, and draw up the list of research priorities.

STUDY OF BIRDS AND MAMMALS IN ECOSYSTEMS

The Paris Conference on the Biosphere concluded that a synthetic and analytical study of ecosystems was necessary. This requires examining the ecological structure of mammals and birds and their involvement in the transformation of matter and energy.

The ecological structure of the vertebrate population should be understood as the relationship and spatial distribution of the number and of the biomass of groups of species with a similar mode of life. Most likely, to appreciate the extent of this similarity, one needs to operate with an ecological classification of animals. The efforts at developing this classification began at the turn of the century. These efforts produced the concepts of "adaptive types" and "bioforms" and "Ecological Equivalents." At present, it is advisable to draw a wide range of biologists into the elaboration of the ecological classification. This classification should cover all animals of the planet; and in conformity with the tasks of biosphere reserves, it should differentiate mammals and birds by the specific features of their relations to the habitat. The latter requirement makes it expedient to build this type of classification on the basis of ecological criteria suggested by A. N. Formozov. Formozov divides animals into biological forms which are associated into biological classes. The characterisitics of biological classes are the trophic relationships of species and the tier of the biogeocenotic cover which is occupied by them; the characterisitics of biological forms are the modes of procuring food, peculiarities of motion, construction of shelters, and adaptation to unfavorable seasons of the year. The similarity of relations with the habitat within one biological form predetermines the similarity of their responses to changes in the conditions of existence and the simlarity of participation in the biological circulation. Therefore, the biological forms of Formozov are functional units of the zoocenoses structure. A classification built on this foundation will render easier the comparative analysis of the structure and functioning of ecosystems of different zoogeographical regions and districts.

Two forms of participation of vertebrate animals in the biological circulation are distinguished in the U.S.S.R. One of them is in the transformation of matter and energy on the separate trophic

levels. This form has had considerable attention in the International Biosphere Program. The research launched by that program apparently should be continued. Its place in the work of biosphere reserves, however, will become clear only after a thorough analysis of accumulated data.

The second form of participation of vertebrate animals in the biological circulation is determined by their influence upon the functioning of other components of the ecosystem. This influence requires further study. The available findings, however, prove its importance in natural processes.

The approved program of biogeocenotic studies in the U.S.S.R. (1971) provides for a quantitative characterization of the participation of vertebrate animals in the formation of the atmosphere's gas composition and in water distribution--the formation of the surface runoff, the distribution of moisture in soil, the formation of the hydrothermal regimen of the close-to-the-surface layer of air, the progress of water and wind erosion, organic and mineral additions to the soil substances and their conversion and mixing in the soil profile, the influence of animals on the growth and development of vegetation, and the elucidation of the role of all these processes in the formation of primary production in the autotrophic cycle of the biological circulation. The study of the mentioned questions should be conducted at biosphere reserves as well. Only in this case is it possible to receive a sufficiently full characterization of the way the reference ecosystems function.

To resolve biosphere problems it is necessary to have a clear-cu idea of how natural ecosystem functions will be altered by man's economic activity. The latter circumstance will uncover the mechanism of anthropogenic peculiarities of the biological circulation which are decisive for the evolution and the destinies of the earth's biogeocenotic cover. In this connection, it is expedient to investigate the taxonomic and the ecological structure of zoocenoses and the extent of participation of animals in the biological circulation of pasture, agricultural, forest, and commercial and recreational ecosystems. Notwithstanding the fact that this work transgresses far beyond the confines of the conventional themes of study at reserves, its implementation should be vested with the staffs of biosphere reserves. This will guarant the comparable, ecological approach to the examination of parent and derivative associations and the uniformity of the applied research techniques.

CONSERVATION OF REFERENCE ZOOCENOSES

At present, practically all biocenoses of the world have been altered by man in greater or smaller degree. It is therefore necessary to identify the degree to which taxonomic and ecological structures of the animal populations in biosphere reserves retain their parent features. The answer to this question is indispensable for a proper characteristic of the territories protected as reference models of nature. The answer to this question demands

large-scale studies of historical ecology at biosphere reserves. In some cases, the results of these studies will make it possible to commence the restoration of parent zoocenoses by reacclimatization of exterminated animals. A well-known instance of this type of reacclimatization might be the successful experiments of settling the beaver, the sable and the auroch in Soviet reserves.

The restoration of the natural structure of zoocenoses might prove impractical without reinstating original plant associations on the territory of the reserve.

The restoration of original zoocenoses requires great caution and is permissible only when based upon an adequate natural-historical foundation. Properly implemented, it will increase the reference significance of the protected ecosystems and facilitate conservation of the genebank of animals and plants and preservation of rare and disappearing species. The specific features of the economy and the mode of life of the population in the districts of biosphere reserves and some other causes, many of which cannot be forseen, might render complete reinstatement of the original zoocenoses impractical or even impossible. It is necessary to provide a system of biotechnical measures supplementing the functions of exterminated animals in such reserve ecosystems. Past experiences have proved that without such measures the development of associations under protection begins to contradict the main goals of reserves' regimens. Abandonment of these tasks may cause the emergence of peculiar ecosystems which have nothing in common with the real reference models of nature. Questions on the possibilities of restoring natural structures and applying biotechnical measures in biosphere reserves have many debatable aspects and merit special consideration.

The conservation of reference systems will be greatly complicated by anthropogenic pressure upon zoocenoses from territories adjacent to biosphere reserves. In the small size we know that reserves in the European part of the U.S.S.R. regularly accumulate ungulates from neighboring districts where they are harrassed by hunters and lumberjacks. The excessive population densities of the animal population that results lead to zoogenic successions of the plant cover. Similar facts have led to a conclusion that the reserve territory does not ensure the regulation of the surrounding associations, and the changes in the latter predetermine changes in the protected ecosystems. K. D. Zykov and collaborators, who have formulated this thesis, suggest that it be taken into consideration when determining the area and the shape of the reserve territory. Owing to historical, social, and economic reasons, however, it is not always possible to take guidance from these recommendations. Therefore, to preserve the reference ecosystems, one has to elaborate a system of special measures protecting the biosphere reserves from anthropogenic processes which are developing on the surrounding territories.

Soil-Zoological Studies of Biosphere Research Stations

by

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Soil animals are an important component of the biosphere. They account for the bulk of the zoomass. If one judges by quantitative indicators (by the volume of transformed energy in particular) soil animals are approximately equivalent to another important member of the heterotrophic complex--saprophilous soil microflora. A close functional relationship has been recorded between these links of heterotrophs: animals are a powerful factor which invigorate microflora activity. The most characteristic and essential components of the animal soil population are saprophages which account for the bulk of the zoomass in all humid landscapes. The saprophilous complex of invertebrates is engaged in mineralization of the decaying organic matter and plays a tremendous biogeocenotic role. The latter consists of the immediate biochemical and physical influence on decaying organic matter and in stimulating the activity of saprophytes. Thus, soil animals, together with the microflora, create the foundation for the basic processes which are decisive for the functioning of the biosphere. Therefore, soil-zoological data are of primary importance in the research into general regularities of the structure and functioning of the biosphere. Extensive data about the role of soil animals in biomes of different climatic belts and zones have been obtained as part of the International Biological Program and summarized in relevant publications (Ghilarov and Chernov 1974, 1975).

Extensive soil-zoological studies have been carried out in the U.S.S.R. They characterize the structure and the biogeocenotic role of the animal soil populations in different zones and altitudinal belts. General regularites of the zonal and regional distribution of the biomass of soil animals have been revealed, as well as the changes in the trophic structure and their biocenotic role. There are numerous data describing the biogeocenotic activity of various groups of soil fauna, the regularities of their territorial distribution, and participation in different types of ecosystems. Methods of integrated, quantitative study of the soil animal populations have been developed, including techniques of experimental determination, estimation, and analysis of different synecological indicators, applicable to the animal population of soils (Techniques of Soil-Zoological Studies, 1975).

In the context of the "Man and Biosphere" Program, experts in soil zoology are facing new tasks. First, they should process the accumulated data to determine the most general global regularities in the participation of soil animals in the functioning of the biosphere. Second, they should increase research into the structure of ecosystems and the trophic-energy processes in the most typical and economically important types of zonal biomes, paying particular attention to anthropogenic influences on the living cover of the Earth.

Changes in original natural communities under anthropogenic influence, are becoming more pronounced. The number of places where the original, natural soils have been preserved is shrinking rapidly throughout the world. Meanwhile, knowledge of the specific features of the organization of original cenoses is indispensable for developing a general strategy of man-biosphere relationship--for the development of a system of measures for maintaining soil fertility, in particular.

The importance and relevance of the study of soil fauna is, therefore, perfectly clear. One should bear in mind the tremendous direct role of soil animals in the functioning of ecosystems and also the possibility of utilizing them for identifying the character and trends of changes in soils, vegetation, the chemical peculiarities of environment, and radioactive contamination (Ghilarov and Krivolutsky 1971). The main principles for using soil animals for identification purposes have been worked out as a general theory of soil diagnostics, based on zoological information (Ghilarov 1965). The task of applying these principles on a larger scale stems from studying the biosphere as a whole.

To answer all these questions, we must initiate permanent studies at stations in the most typical zonal landscapes of different belts and zones, where the most characteristic types of soil can be singled out and used as reference types. The information obtained at these permanent monitoring sites should be used for extrapolation to larger territories.

The system of soil-zoological research at permanent monitoring sites should, to the greatest possible extent, reflect the biosphere's zonal, altitudinal, and regional differentiation. The study areas should be distributed in a way to cover territories with both the optimal and poor combinations of environmental factors for the production processes. First, it is necessary to undertake detailed studies of the structure of the animal soil population and of its geochemical activity in areas with highest biological productivity and a high intensity of biogeocenotic processes. In the temperate belt, this would concern primarily the forest-steppe districts with chernozem soils and broadleaved forests on grey soils. Particularly favorable for integrated synecological studies is the territory of the V. V. Alekhin Central-Chernozem Reserve and parts of the Tula Region. Soil-zoological studies in forest-steppe landscapes and in broad-leaved forests are essential for discovering many fundamental factors of soil animal participation in the production processes

and in the circulation of matter. Soil fauna of the chernozem steppe is extremely rich and varied ecologically (Ghilarov 1960, Chernov et al. 1967, Chernov 1975). This is where the direct animal influence on the soil profile is particularly deep and the zoomass is very high. Characteristic of the area is a high differentiation of the trophic composition (besides the saprophages, there are numerous soil phytophages, predators, and omnivorous forms). This is due to the fact that the forest-steppe is situated in an area particularly favorable for production processes, owing to a balanced hydrothermal regimen (the radiation index of dryness is near to 1). Owing to this, the forest-steppe landscape should be taken as a starting point for the global zonal analyses of the animal soil population. The quantitative characteristics of other biomes should be compared against them.

To determine the complete structure and dynamics of the animal population of soils, research should be undertaken in broadleaved forests. The soil fauna of the broadleaved forests has slightly less taxonomic and ecological diversity than that of the forest-steppe. The biomass, however, is greater here, reaching 2 tons/ha This is due to the abundance of large-size saprophages and particularly--the earthworms.

Particularly promising, in the oak woods, are the studies of general regularities of the functioning of the saprotrophic link of biogeocenoses, the processes of utilizing and incorporating plant remains into the circulation. Oak groves to the south of Moscow and in the Tula vicinity may be used as reference territories

A comparison of landscapes with optimal and poor climatic conditions for production processes is of considerable importance for the understanding of general regularities in the zonal structure of the animal soil population. An increase in dryness results in a sharp decrease in the number of the main links of soil fauna--the saprophilous complex; there is an increase, however, in the specific share of soil phytophages, which play a considerable role as farm pests. The animal soil population acquires many basically different features. Studies in clay, semidesert, and desert areas are indispensable for determining the typical peculiarities of the structure of the animal soil population in arid landscapes. The semidesert territory near Djanybek is particularly suitable for setting up a semidesert station for biosphere research. This territory has a Reserve which belongs to the Forest Studies Laboratory of the U.S.S.R. Academy of Sciences. Particularly interesting in semidesert conditions is the integrated character of the soil cover--the combination of several types of soils on a small area (solonets, chestnut, chernozem-like This demonstrates the specific features of the boundary zone between desert and steppe area. The soil fauna as a sensitive indicator of the geochemical regimens reflects the integrated character of the soil-plant cover. The importance of studying the soil fauna in arid landscapes is related to the problem of aforestation. Communities of soil organisms may serve as a sensitive indicator of geochemical shift during irrigation, melioration of salted soils, etc.

Studies in the desert zone should be conducted at least at two permanent monitoring sites: in clay deserts (particularly indicative are the landscapes of Usturt Plateau) and in sandy deserts near Repetek, for instance. The comparison of the soil fauna of sandy and clay deserts can provide much material for answering fundamental questions about the origin of deserts, the regularities of lasting anthropogenic changes in arid landscapes and also for the elaboration of measures for economic use of soils in arid areas.

North of the forest-steppe ecotone are the humid landscapes where the share of saprophages in the soil fauna increases, while the share of phytophages decreases. The activity of soil invertebrates as agricultural pests goes down in the boreal regions. The animal life in soil and litter in forests plays a considerable role in mineralization and humification of vegetative remains and in drawing them into the biological circulation. It is necessary to establish several stations for research into the soil fauna of taiga forests in the European part of the U.S.S.R. and in western and eastern Siberia. It is particularly important to select sites where it is possible to trace all successional stages leading to mature climax forest stands. The districts where postintensive cuttings are located are favorable for this type of research.

Soil-zoological studies in the Subarctic are of fundamental interest. The general impoverishment of the qualitative composition of the animal world--the simplification of its numerical and trophic structure--makes it possible to conduct frontal examinations of a large number of pedobiont groups. In other words, it is comparatively easy to obtain total quantitative characteristics of communities. This is particularly important for the elaboration of general principles of integrated study of the living cover of the world as an entity. The districts of Taimyr are particularly suitable as reference territories for integrated studies of soil fauna in the tundra since all three tundra subzones are well expressed there--southern, typical, and Arctic tundras. First of all, a study should be made of the typical tundra landscapes which represent the most characteristic peculiarities of Subarctic regimens.

For a clear idea on general patterns of the animal soil populations, we should have information on extreme landscapes--such as polar deserts on Arctic islands. Against a background of considerable impoverishment of the taxonomic composition of the animal world as a whole, the animal life in the surface layer of barren rocks with lichen-algae communities on Arctic islands is most peculiar and relatively rich in number. The population density of *Nematoda*, *Collembola* and enchytraeids in polar deserts is so high that the total zoomass reaches values which are characteristic for much more southern biomes (in some places 10, at times 20 g/m^2). It has been found that the zoomass-phytomass ratio reaches its maximum in polar deserts, which indicates the great part played by the animal soil populations in the total production processes.

Many methodological principles should be followed when studying soil fauna as a component of the biosphere. In particular, it is necessary to take duplicate quantitative censuses of as many groups of invertebrates as possible, using comparable techniques which indicate density per unit of area. This allows estimation of total values which illustrate the role of soil animals in the circulation of matter in communities of different structure. First of all, it is necessary to estimate the total biomass, total metabolism, annual production, etc. It is essential to make a separate count of functional groups which is indispensable for the analysis of the trophic-energy structure of communities.

The quantitative characteristics of the animal population of soil should be strictly related to the structure of landscape; in particular to the peculiarities of the drainage-geochemical processes (Stebayev 1976). Thus, a clear-cut distinction should be made between zonal and intrazonal parts of the landscape and of the corresponding types of communities. The relation of zonal and intrazonal soil types and of their animal population changes in a regular manner in different zones. Under poor conditions (arid and nival) we see a great contrast between soils and animal populations in watershed areas and in the intrazonal biogeocenoses. Here the production of intrazonal communities is the highest in a given type of climate. Thus, in the Subarctic, in nival meadows on slopes, the zoomass reaches the same level as in the chernozem meadow steppe (up to 50 g/m^2) whereas in tundras, no more than 10 g/m^2. Therefore, precisely these elements of the landscape, which usually cover a small part of the territory, are of the greatest interest in evaluating the production-energy potential of biosphere components.

Experience has shown soil animals to be one of the last representatives of the animal population in an environment altered by man. Their communities maintain considerable variety of species and number even in islands of natural vegetation, such as municipal parks and botanical gardens (if these areas are not trampled out by people). For this reason, soil animal research at permanent biosphere stations near large cities, or in areas extensively developed by man, is of particular interest; it may provide us with the most complete information concerning the condition of the animal population and its changes due to anthropogenic influence.

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Entomological Studies in Biosphere Reserves

by

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The study of insects is a major aspect of present-day integrated biogeocenological studies including those in future biosphere reserves. The program, the methodology, and expected results of entomological studies in biosphere reserves are determined by the features and importance of areas singled out as reference territories. The first stage of research is to discover the composition of insect species in the studied territory. Such data can often be obtained rather quickly by analyzing previous studies, not necessarily on the territory of the reserve, but in the same zoogeographical province. As a rule, such data are available; nevertheless, some "blank spots" will definitely be encountered in poorly studied areas. Thus, the primary task in the studies covering biosphere reserves will be to study faunistic material in the given territory and to fill in the existing gaps in particular groups of insects by means of specific studies.

The initial phase should include the establishment of collections and ensuring the necessary and proper long-term maintenance of them in the reserves. This type of a collection need not be a large one. We have in mind a reference bank for the preliminary rapid identification of the most important species directly in the field. Special attention should be given to the species which are specific for the region where the biosphere reserve is established.

The second phase is research into fundamental biology of some species in key plots: i.e., their life cycles, nutrition, habitats role of predators and parasites, etc. Priority should be given to the most abundant species of primary importance for the functioning of the ecosystem, and to those species inflicting harm on man, as well as on species of peculiar zoogeographic and phylogenetic interest, or endangered and therefore protected species. There is usually a rather small number of such forms among insects, although further study might increase the recognized number.

In the first two stages, the administration of biosphere reserves should be able to invite leading specialists from outside (while not having them in the staff) and coordinate these studies within the total research program.

The collection of faunistic material and initial data on the biology of insects will create conditions for more multidisciplinary studies of ecosystem dynamics which are the basic research task of biosphere reserves. Basic trends of research in ecosystem dynamics will include: (1) the study of the population dynamics of important species, (2) the study of entomoconsortiums (or, together with other specialists, consortiums as a whole), (3) the study of succession processes in individual components of an ecosystem, etc.

The study of population dynamics of important insect species is labor-consuming and requires adequate equipment and highly trained researchers.

These studies will be effective if preceded by preliminary work which makes it possible to select the proper objects and to coordinate the research methods with specialists studying other aspects of similar objects.

The study of insects as components of basic consortiums is very promising. It is sometimes possible to single out one species or a limited number of plant species in an ecosystem and to study thoroughly the insects related to these plants. When entomological studies are conducted in comparatively uncomplicated phytocenoses, characteristics of insects which belong to several leading consortiums make it possible to contribute to the study of the fauna, biology, and the structure of associations.

One of the most important fields of study in biosphere reserves is a thorough analysis of consortiums including the inhabitants of the rhizosphere, i.e., the soil insects.

Besides the consortiums, the biogeocenosis incorporates other points of animal concentration. First, there are the decaying plant and animal remains: Wood, fungi, decomposing leaf litter, animal carcasses, etc. In some cases, the animal associations which are formed as a result of this type of accumulation of organics, specifically if their decomposition has been on for a long period, are very complicated and subjected to regular changes in time (succession). The study of these successions is important; without it, it is difficult to understand the peculiarities of the circulation of matter.

Taxonomic and ecological diversity of insects is many times larger than the diversity of plants and higher animals. The tasks of entomological studies in the biosphere reserves are not independent but subordinated to the overall program of research into bioenergetics of the ecosystem. The analysis of the entomocomplex is in many cases determined by the preceding analysis of phytocenosis. In many cases, it is necessary to depart from species and genus level of study, and to analyse the entomofauna by its role in the ecosystem based on trophic groups--for instance, soilformers, saprophages, xylophages, foliage consumers, etc. It is expedient to conduct an integrated study of insects-saprophages and saprophytic fungi to obtain a quantitative

appraisal of energy transformation. These integral conclusions are based, naturally, on the summation of the results of the earlier-mentioned phases of research.

Consequently, the study of insects on three consistent levels--faunistic, biological, and synecological--will make it possible to determine their importance in the functioning of reference ecosystems.

Of the numerous possibilities of illustrating the aforementioned fundamental tenets relating to entomological studies in biosphere reserves, it seems to be more advisable to consider the experience of organizing permanent studies in arid zones (including saksaul[1/] forests) and the study of the ecology of xylophilic associations in forest zones. Since 1970 the Joint Soviet-Mongolian Biological Expedition has been conducting an in-depth biogeocenological study of entomocomplexes in the main natural zones of the Mongolian Peoples Republic--the mountain-forest-steppe, the dry steppe, and the desert-steppe at three stations: on the eastern slope of the Hangai Mountain system, in Central Mongolian steppes, and in the Gobi Desert. The studies are sponsored by the Institute of Biology of the Academy of Science of the Mongolian Peoples Republic, and the Institute of Evolutionary Animal Morphology and Ecology, U.S.S.R. Academy of Sciences.

The aim of these studies is to describe the entomocomplexes of the main natural zones of the Mongolian Peoples Republic in biogeocenological terms--to determine the composition and the structure of populations, establish its relationships with other natural factors, and appraise the place and importance of insects in biogeocenoses. Studies of this type are being conducted in central Asia for the first time, although some previous experience accumulated in the past decade during the work in Central Kazakhstan.

The following main questions have been studied for 5 years: (1) the general faunistic composition of each station as a whole. For the main types of biogeocenosis (stationary sections) it helped to determine the distribution of insects and the basic components of every association; (2) the general number of insects and their dynamics which help to determine the dominants and appraise their role in each association; (3) the phenology of life cycles determined by specific continental and arid conditions in central Asia; (4) description of the preimaginal phases of dominants; (5) the consortive relationships of insects and the extent of damage caused to the main species of plants; (6) the determination of bioforms (pedobias, herpetobias, phytobias, aerobias) and their respective participation in biogeocenoses and distribution of the entomofauna in biohorizons; (7) the relationship of the main trophic groups (phytophages, saprophages, predators); (8) the general appraisal of the insect biomass and its influence upon biogeocenosis; (9) the economic importance of the prevailing species, etc.

[1/] Saksaul is *Haloxylon* throughout this article.

In conjunction with the detailed study of associations in key plots, important supplementary data can be obtained through less-detailed studies on the linear profile which also covers secondary biocenoses. This profile can range from 10-15 to 70-80 km. A combination of data covering the profile and the key plots makes it possible to describe the entomocomplexes of a large natural area in an integrated manner.

Studies have indicated sharp distinctions in the group composition and in the zoogeographical structure of each zone. Even within one zone, it was found that different types of biogeocenoses differ sharply in genesis. Many insects proved to be important edificators of individual associations, subzones and zones. Thus, leaf beetles play an exceptionally important role in identifying the boundaries of desert steppes, on the one hand, and of plains and mountains on the other. The most typical arid herpetobionts, which lack narrow trophic specialization and are, therefore, practically independent of the type of plant association, can be much more sensitive indicators of abiotic factors and of the biogeocenoses as a whole than the vegetative associations. Thus, a regular substitution of certain types of insects by others has been observed in a vertical profile of the desert-steppe station in a range of 1 000 to 2 000 m above sea level and on a length of 72 km. The zone of spread of each species is quite insignificant (up to 4-5 km) which corresponds to a change in the altitude of several tens of meters. This concerns primarily the darkling beetles, the most clearcut edificators of lower rank associations in the arid zone.

Sharply mosaic spread of insects related to individual large groups of plants has been found in all arid associations. This feature immediately identifies the body of plants whose consortive relationships are to be identified. The African millet (caragana), wormwood, Nitraria, and saksaul proved to be the fauna concentrates in the Gobi. Approximately 70 species of insects were identified for saksaul. It was also shown that the entomocomplexes of middle Asian deserts differ greatly from the central Asian deserts both by composition and structure of the population and by the absence of spring ephemers in the sharply continental conditions of middle Asia.

The entomocenoses of saksaul forest were studied by the associates of the Institute of Evolutionary Morphology and Animal Ecology in the Karakum Desert in 1970-1971.

After analyzing all literature on the fauna and ecology of the saksaul forest insects, the dominant species--saksaul--was taken as the basis for the study of the consortium.

Using the technique of entomological net sweeping in saksaul crowns, we have registered representatives of 10 families (outside of the specifically studied groups) in the spring. The special study of gall-producing insects as pests of saksaul made it possible to identify 32 species of this group and to suggest that gall-producing insects consume up to 10% of the energy resources the plant expends on vegetation. As in other basic groups of

saksaul forests, a special study was made of the Orthoptera insects, represented by five orders and ants. In particular, 16 ant species were subdivided into trophic groups; the number of their nests per 1 ha was determined, as well as the intensity of feeding and the importance of ant species in the biogeocenosis of the saksaul forest.

Special attention was given to soil insects which were studied by soil sampling on an area of 50 x 50 cm and additionally--by direct investigation of the insects of the plant rhizosystem. The biology of 35 species of insects which develop in plant roots was studied. A special program was set up to study the characteristics and significance of a "background" species, the large Caspian termite.

As a result, the faunistic and biological stages of research, and to some extent the synecological stage, were carried out in the reference saksaul forest.

The entomocenoses of temperate forests are considerably richer than those of saksaul forests. Accordingly, one can encounter much more difficult problems there.

The consortive approach to the study of entomocomplexes requir a similar study of the entomoconsortium of dominant arborous species--as was done in the saksaul forest. If insects associate with coniferous trees are studied in a coniferous forest, and those associated with the birch are studied in a birch forest, etc., we can hope to make a fundamental contribution to the study of the major links of the appropriate forest entomocenosis. Afterwards, it can be extended to the study of secondary links.

There are, however, specialized groups of insects in humid forests which need to be separately studied. These include, in particular, insects which destroy dead wood. As the result of long-term study in the Palearctic, it has been possible to trace a 5-stage succession of complexes of xylophilic insects. For every stage, species composition for the inhabitants of the bark and of the wood proper was separately ascertained. The trophic relationships of insects have also been described. The approximate significance of individual groups of xylophages as wood destroyers was also determined. The zoogeographical aspect of the formation of xylophilic entomocomplexes has been studied. The results referred to the Far East have been partially publishe

In whatever part of the forest zone a biosphere reserve is established, its research program should include the study of such diversified associations of insects as those inhabiting wood.

In conclusion, it should again be emphasized that successful study of the entomofauna of biosphere reserves will permit us, on the one hand, to define the degree of anthropogenic influence on the entomocenosis as an integral part of biocenosis; on the other hand, we will be able to indicate possible protective measures for the respective entomocenoses and individual species.

Hydrobiological Studies in Biosphere Reserves

by

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GENERAL CONCEPTS

Though nature conservation is an extremely difficult undertaking, a few simple truths should be pointed out. First of all it is evident that natural biological systems are shrinking in size and are being destroyed. Hence the necessity of identifying these changes with the idea of preventing them.

Further on, it should also be noted that the unwanted biological consequences of damage to environment are alarming. Therefore, the priority should be given to monitoring biological systems using biological indicators and those of the abiotic factors which control the biological processes or which cause unfavorable changes in them.

The monitoring program in biosphere reserves should provide for an inventory of the species composition, the structure and functioning of terrestrial, soil, and aquatic biological systems. Further on, we shall consider the monitoring of inland water biological systems.

Lakes, with their population, comprise native centers of natural complexes since they receive dissolved and suspended materials with the discharge from their water basin. L. L. Rossolimo (1975) drew attention again to the fact that the lake, as an accumulation system, is a source of information about the changes occurring in its water basin. Therefore, it seems that lake associations represent a significant object for monitoring the state of the environment and the damage caused to it.

Information is necessary on the composition of lacustrine population and the structure and functioning of communities in an undisturbed environment. Monitoring of a standard list of biological indicators should be conducted for many years. Hence, the necessity of having inland water reservoirs in every biosphere reserve for hydrobiological monitoring.

Part of this work consists of summarizing the available scientific information. A number of institutions in the U.S.S.R. have also accumulated this type of information. Among them: the Institute of Biology of Inland Waters and the Institute of Lake Studies of the U.S.S.R. Academy of Sciences, the Institute of

Hydrobiology of the Ukrainian Academy of Sciences, the Institute of Limnology of the Siberian Branch of the U.S.S.R. Academy of Sciences, the Institute of Biology and Geography of the Irkutsk University, and others (Zhadin and Gerd 1961, Kozhov 1962, Rybinsk reservoir 1972, Tseeb and Maistrenko 1972, etc.). Among completed programs we may note the extensive research which elucidated regularities related to the formation of the population of new reservoirs (the Institute of the Biology of Inland Waters, U.S.S.R. Academy of Sciences).

It is necessary to get an idea of the normal and disrupted level of the monitored characteristics.

Monitoring of lake organisms may be carried out on the following levels:

1. Communities--species composition, structure, and functional indices. Most likely the functional summarized characteristics of communities cannot be regarded as indices which describe their state well. Plankton can serve a swiftly responding and methodologically convenient communities.

2. Populations--quantitative dynamics in unaltered and altered environments.

3. Indicator species.

4. Physiological level (Larkin and Northcote 1969, Frey 1969. Smirnova 1962, 1968, and 1974).

5. Molecular level--the determination of the state of environment by metabolic links which are vulnerable to toxicants and other similar influences.

6. Special monitoring of mutagenic, teratogenic, carcinogenic influences.

7. Registration of abiotic environmental factors.

8. Registration of the natural cycles of biologically active substances.

ZOOPLANKTON

Zooplankton form convenient communities for monitoring the state of environment. Unlike phytoplankton, zooplankton are less dependent on regular changes of chemical factors of the environment and reflect more durable and larger changes. The latter may be a result either of the natural development of lake communities or of man's intervention in the life of a given lake and the discharge of water into it or into the surrounding landscape. It has been found that lakes which are withdrawn from strong economic influence retain the character of their plankton community for dozens of years.

There is information stating that the species composition and the quantitative indices of zooplankton are stable for periods ranging from 16 to 26 years (Smirnov 1973).

Also known are changes in the dominance of particular species. Thus, the maximum number of *Daphnia longispina* in Upper Boden Lake in 1952-1962 increased more than five-fold compared to 1932-1935; the survival of some of the females in plankton continued up to February whereas earlier they used to disappear in August (Elster and Schwoebel 1970). The domination of *Daphnia* in 1949 in Lake Cuteney (British Columbia) was replaced by the prevalence of *Diaphanosoma* in 1969 (Zyblut 1970). Intervention into biological relations in a lake by way of introducing new species of fish resulted in a decrease in the crustacean plankton, extraordinary numbers of some species, and greater seasonal fluctuations (peaks) of species. Thus, 6 years of observation at Snuff Lake in Canada revealed an unusual peak of *Chydorus sphaericus* (Anderson 1972). Planktonic crustaceans, which were destroyed by a single introduction of 0.75 mg/l of rotenone, were restored in 3 years (Alberta, Canada; Anderson 1970). Zooplankton, however, failed to be restored for 6 years in Paul Lake (British Columbia, Canada) after it was suppressed by 0.004 mg/l of toxaphene (Larkin et al. 1970).

Brooks (1969) emphasizes that the influence of pollution upon zooplankton may be a result of several developments, since a dislocation of the environment may influence many links of the biological system - from algae to fish.

INVENTORY OF THE SPECIES COMPOSITION OF FAUNA AND FLORA

The inventory of the main components of biological systems - species - is necessary to determine the biological processes in these systems and the changes in the sytems. This, however, is a difficult task which in most cases cannot be settled even at sites of stationary monitoring. B. A. Tihomirov (1971) stated that the inventory of species is a matter of high priority and necessity in biocenological studies. The difficulties involved in the task were even noted in the literature. Thus, R. Dajoz (1975) noted: ". . . from the practical point of view the study of all components of a biocenosis is next to impossible and was never undertaken, since it involves the extremely difficult problem of identifying all the species which exist in it. More often, one or several well-known groups represented by different, rather numerous and ecologically diversified species are studied."

Water biologists and geobotanists also seek complete inventory of the species composition which is limited by practical difficulties only. It is a difficult task to determine the number of species in a biological system. The number of recorded species in limited areas, like lakes and in artificial reservoirs with an altered natural environment, is about 2,000 (according to prolonged or stationary monitoring, not counting the species of bacteria). Single examinations almost always give an incomplete list which is due to seasonal changes in the number of species. The accuracy of

data given in literature in many cases is directly proportional to the amount of effort, rather than to the real number of species.

It is also noteworthy that in the average living conditions, the number of species within an association is not great. They are interrelated by strong or weak, positive and negative relations. The large number of species in itself creates the possibility of a variety of solutions in definite biological situations. According to B. A. Tikhomirov (1971): "The species abundance in a definite area is an indicator of life activity, self-regulation and of a relative stability of the biogeocenosis."

The number of species is small when some factors of the environment reach extreme levels. In connection with this, extremely salty reservoirs and thermal springs represent the few situations for which the number of species has been accurately determined, since the number itself is small.

Owing to the unfeasibility of a complete inventory of species composition for the appraisal of the state of the environment, we should draw up a list of standard groups of species which are related taxonomically (taxocenoses) for whose inventory we can provide an adequate number of specialists. These groups should include, for instance, insects, crustaceans, and diatomic algae.

The list of species of this cenosis might include mass species which can be found annually as well as rare species which are not found every year. For instance, the cladoceran *Ophryoxus*, which has been recorded in the Rybinsk reservoir, is not annually found; but there are years when it is very abundant. As for Lake Glubokoy (Moscow Region), the presence of the *Holopedium (Cladocera)* has been recorded; but it has been found only twice during an interval of many years.

If there are no considerable changes in environmental conditions, the list of species varies little in many years; at any rate its changes are rare. Thus, the species composition of zooplankton in Maggiore Lake, Italy (Baldi 1951) has not changed from 1909 to 1950. That of Lake Estwaithe Water, Britain (Smyly 1972) increased from 1923 to 1968 only by the appearance of one species (*Cyclops strenuus*); that of Lake Glubokoye, Moscow Region (Matveyev 1975) from 1954 to 1975 lost one species, namely *Mesocyclops leuckarti*.

The species composition for many years might vary due to direct or indirect human influence. The disappearance of species should be regarded as an indication of considerable changes. This opinion may be supported by unsuccessful attempts at complete extermination of species, which for some reason were deemed undesirable - parasites or farm pests.

A drop in the number of species has been recorded as a result of pollution - for instance, the number of species in Volga River zooplankton were reduced after oil pollution (Konstantinova 1956).

Even in oligomixed biocenoses (consisting of a small number of species), the inventory of species composition requires the work of highly trained specialists. Though there is a small number of species inhabiting salt lakes, we know of 29 species of *Dunaliella*, most of which can be found in strongly mineralized reservoirs (salt lakes) (Masyuk 1973).

Such a work is rendered more complex with the progress of taxonomy. There are poorly studied groups with species which are not easily identifiable. For instance, in may cases it is difficult to determine, or impossible to identify, the dipteran species by their larvae. With the progress in taxonomy some "old" species are being subdivided into several "new" species or, the other way around, they may be combined into one.

A large number of keys for species' identification is necessary.

THE STUDY OF THE HISTORY OF COMMUNITIES BY LAKE SEDIMENTS

To have an idea about the trend of recorded processes, we have to obtain series of data covering many years. The present rate of technogenic dislocation of nature makes it sometimes necessary to have an immediate appraisal. Such secular series of data on the development of communities can be obtained by examining the remains of species in the bottom sediments of lakes which, in this context, are a unique natural object.

Bottom sediments accumulate plants and animal remains in chronological sequence and in definite proportional quantities. The bottom sediment contains the remains of species which belong to the community of the lake proper. They might also include remains of communities from the surrounding landscape in the form of pollen, plant tissue, and seeds. Lake bottom is one of the main natural objects which helps to study historical biocenology and obtain results which are unaccessible through other means. Mulden (1969) remarked quite correctly that at the present rate of pollution of our environment, it might happen that paleolimnology will be the only technique for studying and understanding the development of natural communities.

Lake beds preserve fragments of plants and animals inhabiting the littoral, pelagic, and benthic zones. This type of biological analysis of lake beds is quite adequate since it is representative of the population of all the main zones of a reservoir.

The biological analysis of the bottom of reservoirs might also be applied to historical studies using ground cores, or to analyze the present biocentological type of reservoir using the ground specimens from the bottom surface. The processing of a single sample of the bed gives a fuller inventory of the water lea species than live material for several time periods from a

number of stations, as it has been demonstrated in several reservoirs. Thus, single samples of bed from six lakes in Wisconsin, U.S.A. revealed six species of *Chydoridae* more than all the previous tests over many years; they failed to find only two species (Frey 1960). The examination of seven silt samples from the Ivankovskoye reservoir revealed 31 taxons while only 29 were known as a result of a number of previous collections by special parties. The analysis of single samples taken from ditches of Lake Narskoye, Moscow Region gave a fuller list of species than the samples of live material taken monthly for 2 years; the ditch bed alone revealed eight taxons, whereas only three taxons were in the samples of live material.

The time represented by the cores of lake sediments can reach a million years as in a core of 192.7 m from Lake Biwa (tertiary lake in Japan, Horie 1972, 1974). Usually the cores of lake sediments cover approximately 10,000 years, which includes the time of development of the main civilizations of our world.

The integrated biological analysis of lake sediments incorporates botanical and zoological analysis of lake organisms, pollen analysis, carpological analysis (seeds), the analysis of tissues of macrophytes, and the chemical and physical characteristics. Model works in the field of integrated analysis of lake ground have been carried out by N. V. Korde (1960) and under the direction of G. Hutchinson (1966, 1970).

There has been a considerable development recently in the analysis of animal remains in the bed; primarily of the prevailing fragments of Cladocera (carcinological analysis), insects (mainly of the head capsules of the chironomid larvae), sponges (by spiculae), Protozoa (by their "houses") and some others (Frey 1958, 1959, 1964, 1969a,b, etc.).

It has been proven that zoological analysis of the sediments explains a number of peculiarities of the communities and environment, which are not reflected in plants. Our carcinological analysis of European and Mongolian lakes brought to light several typical cenoses which differ by the dominating species, characteristic successions, and features of initial stages of the formation of the cenosis of Cladocera. More often, but far from always, there are cenoses of *Bosminetum*, *Chydoretum sphaerici*, and *Biaperturetum affinis*. It has been found that cenoses of one and the same types of Cladocera and successions of one and the same type are found in European and Mongolian lakes, which are far from each other.

As a rule a community of water fleas, once it passes the first stage of development, preserves its qualitative type for a long time--with moderate fluctuation. According to Goulden (1969), in the first phase of the appearance of water fleas in a lake, one or two species of *Chydoridae* are extremely abundant, while the others are rare; then comes a phase during which the conventional species become less conventional and the rare ones, less rare; in the third phase, the community is supplemented with rare species.

e increase in the species diversity may commence with the ginning of the formation of association and continue for 0-1,000 years. If, subsequently, there are environmental sturbances owing to the changes of the climate, eruption of lcanoes, or man's activity, the species' diversity might drop d return to the initial stage.

Historical data on the development of biocenosis might cilitate the appraisal, verification, and forecasting of ocenotic regularities studied at modern lake communities, cluding the historical continuity of the present biocenotic tuation.

The carcinological analysis of lake sediment demonstrates thropogenic disturbances of the environment. Thus, Goulden has monstrated that the periods of strong increase in the number of ter fleas in the East White Water Lake (Great Britain in the st-Atlantic time) coincide with the appearance of neolithic man d with the development of the economic activity of the Normans oulden 1964). The number of *Chydoridae* in the La Aguada De Santa a Vjeha Pond (Guatemala) increased greatly in the upper 15 cm of diments which was preceded by a large volume of burnt remains which st likely are the result of brush burning to clear the area that s undertaken in approximately 1760 (Goulden 1966). A strong in- ease in the relative abundance of *Chydorus sphaericus* in the upper ter of the bottom layer in Lake Nero (Yajoslavl Region) coincides th the period of intensive economic activity in Rostov and environs he studied core was taken 800 m away from the town site). in the relative volume of the remains of *C. sphaericus* was ted in the ground - from 8 percent at a depth of 20 cm to percent on the surface. This was found to be a result of rtilizer influence (Mackenthun 1966).

The biological analysis of lake bottom sediments indicates the imary importance of the structure of a community as an indicator, mpared to the indicator importance of species. Indeed, the st of species of water fleas in the history of a lake community es not change often, whereas the numerical relationship changes a characteristic way and demonstrates the real successions and anges in the environment.

The time sequence of deposits is preserved notwithstanding a rtain redeposition owing to the activity of bottom animals and drological processes (Frey 1969b).

The limitations of the biological method of investigation of ttom deposits in water reservoirs are associated with the fact at not all species are preserved in the ground. Thus daphnias, ich are known to predominate, in many cases are rather poorly presented. It is difficult to draw conclusions owing to the ct that there are different types of lakes in different geo- emical provinces and different zoogeographical zones. The mber of monitored objects has to be increased in order to present different types of lakes.

It is desirable to develop large-scale integrated biological studies of lake deposits, which definitely facilitate the solution of theoretical and practical ecological problems. Important, in connection with the problem of conserving man's natural environment, is the large-scale application of integrated biological analysis of the upper layers of lake bottom deposits, which illustrate historical changes, including the period of recent industrialization and widespread use of chemicals.

A permanent program of monitoring, using several biological indicators, is in progress on Lake Glubokoye, where one of our oldest lake biological stations (founded in 1891) is operating. A rather large normal range in the level of indicators has been found to describe the state of the zooplankton community and the physiological condition of fishes, in particular the differences for different years (data of V. F. Matveveva and L. I. Smirnova).

The identification of anthropogenic influences is rendered more complicated by the presence of natural fluctuations, both short-term and long-term, by the existence of different types of lakes, by their location in different geochemical provinces and biogeographical zones, and by the natural production of biologically active substances.

The following scientific and administrative questions have to be considered:

- the minimum list of lakes for monitoring biological fresh-water systems;
- a list of monitored communities, species, and indicators;
- periodicity of observations, techniques, the amount of obtained data, and methods of processing and evaluation;
- intercalibration and standardization of instruments and techniques;
- coordination with other international organizations and unions;
- the training of observers, financing, and legal aspects; and
- ensuring taxonomic studies and establishment of centers for identification of species and taxonomy.

Implementation, today, of methods that analyze, at various levels, our disturbed natural environment will determine tomorrow's degree of success.

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The Ecology of Microorganisms and Biosphere Reserves

by

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Bacteria are, most likely, the last remaining group of living organisms in need of protection by means of establishing biosphere reserves. No matter what extent the technogenic changes of the biosphere may reach, bacteria will find a place in life, even if they have to inhabit the cooling pipes of atomic reactors, as they are doing at the present time.

The biosphere reserves are established to protect the flora and fauna in natural conditions, i.e. to preserve the gene pools; however, from the point of view of some microbiologists, bacteria in natural environments should not even be considered an object of microbiology, but rather should be classed with nature-study. These microbiologists suggest that bacteria are an object of research only when isolated into pure culture in a nutritive medium of a definite chemical composition. This point of view has been formalized by the 1975 Bacteria Nomenclature Code. The logic of this trend reduces the world of bacteria to an aggregate of standard culture in collections, and the first accidentally isolated clone is recognized as the standard. Subject to protection is the gene pool amassed in collections (Zavarzin 1974).

In contrast, there is a biogeochemical trend of thought which has been developing in recent years, and which investigates the rate of biochemical transformations, carried out by microorganisms in nature, without determining the specific agents of the process. The rate of reactions is studied by sensitive techniques of modern chemistry, while biochemical processes are distinguished from abiogenic ones by conventional techniques (traditional for the 19th century) in which sterilized and nonsterilized samples of water or soil are compared.

The formation of ecological microbiology which began in our country on the basis of works by S. N. Vinogradsky and B. L. Isachenko, requires another approach. The motive power of any biogeochemical process in this case is the specific group of microorganisms which act as catalysts of the process. Consequently, priority in this case is given to a system of microorganisms endowed with specific functions like that of anaerobic decomposition of cellulose, methane production, reduction of nitrates which interact with a system of external conditions--the rate of arrival of oxygen, of the allochtonic organic matter, sulphates, and calcium. The final result is an overall pattern which describes the interaction within sulphureta or methantank.

recisely, this trend yields the most data about new micro-
rganisms.

Ecologists of bacteria are, more than anyone, aware that there s no sense in protecting a species in nature. The necessary hing is to protect its life conditions. Such biotopes can be ery small, like thermal springs where peculiar cenoses of rocariotic organisms exist. Just a few of these Procaryota have ecome available for laboratory examination, and even that happened nly recently. Peculiar cenoses develop on oxidizing sulphide eposits, ferrous springs, etc. In general, it may be said that he microbiologist is interested in protecting such places in ature where we currently see intensive geochemical processes.

Microbial cenosis, however, requires an ecological approach ot only in these peculiar places. It is precisely the micro- lora of regions where the processes are at equilibrium and where he arriving substance is completely processed at the geochemical arrier, the durable existence of which is possible while it is aintained by microorganisms. Precisely, this microflora is the ost difficult to cultivate in laboratory conditions (Zavarzin 1976).

This shows that our knowledge of the group and species com- osition of microflora, in its main spheres of habitation--including aters and soils--is insufficient. Nevertheless, the available ata can be regarded as adequate for formulating and even resolving ome questions on the role of the microbiological factor in the iosphere and in the protection of the environment.

Let us now examine the micropopulation of the soil. The iversified microworld of the soil can be divided into groups nterrelated by the influence of a range of factors, the first eing metabiotic factors (Mishustin 1972). This covers the ollowing groups, each incorporating many genera of micro- rganisms belonging to various systematic groups:

1. Saprophytes (zymogenous microflora)--decomposing plant and nimal remains.
2. Mineralizers of humus (autochtonic microflora).
3. Oligotrophs--mineralizers of residual substances of various rigin.
4. Autotrophs--organisms which transform mineral compounds nd whose metabolism is based on oxidation of different inorganic ubstances.

The absolute number of microorganisms in different soils is ot the same. From north to south, the soil mass becomes in- reasingly enriched by microflora. Accordingly, there is an ncrease in energy of microbiological processes. In the main, his is a reflection of the temperature factor (Mishustin 1947).

A similar pattern is observed in the grouping of the auto- htonic microflora. The ratio of the saprophytic and oligo- rophic microflora narrows with transition from north to south. n explanation is that the products of organic decomposition

(plants, animals) in a colder climate decompose slower which makes possible the accumulation of a larger mass of oligotrophs in the soil.

To understand the species composition of the mentioned groupings requires the pooling of efforts of different specialists. At the present time the most extensively studied are the saprophytic organisms. A series of species of bacteria, actinomycetes, and fungi have been identified as indicative for certain soils. It is common knowledge that most microorganisms have a tremendous range of natural habitat. It is also determined, however, that optimum conditions for reproduction of certain species of microorganisms develop only in certain soil-climatic zones. Therefore, the spectrum of dominant species for definite soils is highly specific. The confinement to definite types of soil was also observed in some representative of the autochtonous microflora.

The oligotrophic microorganisms are much more numerous than the saprophytic microorganisms. Their detailed study is only in its initial stage. Preliminary data give grounds to conclude that here we commonly find highly interesting (morphologically and physiologically) microorganisms.

The natural cenosis of microorganisms changes radically when soils are cultivated (Mishustin and Pertsovskaya 1954). Even the mechanical effect of ploughing alters the established environment. The improvement of the air and water regimens in the soil intensifies a number of processes and alters the compositon of soil micropopulations. The influence of chemicals (fertilizer and pesticides) aggravates this process. The composition of the micropopulation as a rule, is substantially altered by cultivation and becomes similar to the soil microflora of a more southern zone.

The explanation of the influence of the soil cover upon the environment--the sources of water supply and air--should be carried out by comparing the processes in the natural environment and in the conditions produced by agriculture. This affords the possibility of understanding not only the scientific aspects, but also the essential practical questions (transport of minerals and organic matter from soil to water courses, formation of toxic compounds, isolation of gaseous products from soil, etc.). It is also known that soil cultivation is a source of a number of compounds which worsen the quality of water, like nitrates, pesticides, etc. Therefore, the knowledge of the transformation of these substances in different soils can offer valuable practical information.

The influence of soil on the atmosphere is less clear. Therefore, we have decided to discuss this in more detail.

The present atmosphere took shape on the Earth when the surface layers were unaltered by human activity. At a time of increasing pressure upon the resources of the Earth, it is doubtful that the atmosphere will be able to reestablish its composition. The

elevant argument, usually, is the annual increase in CO_2 by 0.2 rcent throughout 1958-1969. Study of the chemical composition the atmosphere's lower levels depends upon disruption of the ubtle balance between the formation of trace quantities of bstance from various sources and removal of these substances by rious mechanisms (Rasool 1973). The time of presence for asily soluble components of the atmosphere is several days, hile for substances which are difficult for solution, the time s measured in years and even dozens of years. The available stimates of the sources of microcomponent entry into the atosphere indicate that the value of technogenous production is sually less than 1% of natural biological sources; for some omponents, like nitrogen oxide, however, it reached several ercent. Thus, on a global scale, the violation of biological rocesses in the biosphere can affect the composition of the tmosphere greater than the local production of gases by industry.

Lovelock and Margulis (1974) some time ago, comparing the omposition of the Earth's atmosphere with the atmospheres of the ifeless Mars and Venus, concluded that the Earth's atmosphere oes not agree with the expected surplus of nitrogen. It is nown that nitrogen in equilibrium (thermodynamically conditioned y the composition of the Earth's atmosphere) should have passed nto nitrates of the ocean. Lovelock and Margulis suppose that hotodissociation of water vapors could have ensured this reaction y an adequate amount of oxygen.

Whatever the original composition of the Earth's atmosphere, t may be definitely stated that an atmosphere similar to the ontemporary one had been formed by the time eucariotic organisms ppeared in the Earth. Possibly the oxygen content in that tmosphere was lower than when multicellular animals and plants irst appeared. This follows primarily from the fact that all ucariotic organisms are aerobic. Thus, an atmosphere qualitatively similar to the contemporary one was formed in slightly ore than 2 billion years of the existence on Earth of a procariotic ecosystem. Hence, procaryotic organisms are capable of nfluencing the components of the atmosphere and possibly, aintaining its composition even at the present time. This idea an be verified by comparing the possibilities of procarioties nd eucariotes.

Among the soluble gases, the most important is carbon dioxide hose cycle has been studied in considerable detail. The biological peculiarities of carbon dioxide metabolism in growing lants, besides the technique of assimilating it are also characteristic of the procariotic cyanobacteria--the ordinary inhabitants of internal reservoirs. The products of their gas etabolism enter the atmosphere, prior to becoming balanced with he water mass of the ocean. The concentration of carbon dioxide harply increases in the soil air, where it reaches 10%. Two hirds of this carbon dioxide is formed in the respiration of icroorganisms. A question arises, as to what extent the acceleration of the decomposition of organic substances in ultivated soil, with its better gas metabolism, facilitates the ntry of carbon dioxide into the atmosphere?

Oxygen produced in photosynthesis is balanced in the geochemical cycle with carbon dioxide. It polluted the original atmosphere of the Earth, appearing in great volumes as the result of the photosynthesis of cyanobacteria. Its low concentrations, in the order of 0.1% of the present, could have appeared as the result of abiogenic reactions. This concentration of oxygen in presently known aerobic organisms is applicable for microaerophilic bacteria like spirillas and hydrogen bacteria. The present-day concentration of oxygen is close to the top limit for many organisms, bacteria included. Great concentrations of oxygen are controlled by its accelerated consumption for decomposition of organic substances as oxygen blast in aerotanks. [illegible] green plants, which have substituted cyanobacteria in the ecosystem, perform the same role as their precursers; but in the quantitative aspect, their contact with the atmosphere is more effective. The relationship of higher plants with the remaining gases is accidental and at times pathological as in plant-indicato of pollution.

Nitrogen in anabolism is utilized by a variety of different procariots possessing the nitrogenase enzyme. Eucariotic organism do not have this ability. The enzyme, with its genetic apparatus, might be passed from one bacteria to another; the higher plants, notwithstanding all evolutionary advantages, are confined to bacteria-symbionts. The ability to fix nitrogen is possesed by many anaerobic organisms, like clostridias and sulphate-bacteria and by some aerobics, including the corinebacteria and the blue-green algae. The global volume of azotofixation is so large that, according to some estimates, it shifts the balance to nitrogen binding.

The main product of binding is ammonium, which appears in the atmosphere over places of decomposition of organic remains. The curve of its distribution in the atmosphere indicates the existenc of source and discharge near to the earth. The pathways of its conversion, unassociated with anabolism, are fully preconditioned by procariotic microorganisms--nitroficators which develop oxide forms of nitrogen: nitrites, nitrates, and nitrous oxide. Ammonia production is 1,000 megatons per year.

Nitric oxides appear in the disbalance of the microbial ecosystem whenever there is an increased formation of nitrites. The annual output of nitric oxides by soil bacteria is estimated at 1,000 megatons compared with the 50 megatons of technogenic origin. Nitric oxides are the main propellants of the photochemical cycle in the atmosphere. Though their formation by microorganisms has been known since the 1880's, the microbial aspects of their transformation in nature has not received due attention. The activity of specific groups of bacteria, nitrificators, and deniftrificators is associated with nitric oxides.

Nitrous oxide holds a special place, owing to its poor solubility and reactionability. In nitrification, it can comprise up to 20% of oxidized ammonia; in denitrification its

amount varies, comprising a noticeable part of the gas. Besides biological reactions carried out by microorganisms, we do not know any ways of the formation of this gas with an annual output of 600 megatons. The only means of removal, not counting photodissociation in the stratosphere, is consumption by denitrificators in anaerobic conditions.

The entry of nitrogen into the atmosphere is associated with the functioning of a specific group of denitrificators--optional anaerobic organisms which intensively reduce oxidized nitrogen compounds to molecular nitrogen even at low oxygen concentration. This function is only characteristic of procariotic organisms, and apparently nothing but this function equalizes the thermodynamically possible accumulation of nitrates in natural waters.

We have not touched upon the nitrose-compounds formed by microorganisms even though they are of physiological importance without playing a qualitative role in the atmosphere.

Hence, completing the review of the influence exerted by microorganisms on the nitrose components of the atmosphere, it may be stated that bacteria could have both formed the present-day nitrogen-containing atmosphere of the Earth and maintained its composition. They and they alone, of all living matter, possess the indispensable enzymatic systems to exercise that function.

The next group of microcomponents of the atmosphere is comprised of combustible gases. It is expedient to start reviewing them by taking up hydrogen which, according to many geochemists, was an important component of the Earth's original atmosphere. It is practically nonexistent in modern atmosphere. Its sources are the eruptions of volcanoes and the decomposition of organic matter in anaerobic conditions, where it is an indispensable product of oleo-acid and formic fermentation. In the anaerobic zone, however, this gas is consumed by specific groups of microorganisms: sulphate-reducing, methane-forming, homo-acetic, and photo-synthesizing ones. The product of sulphate reduction is hydrogen sulphide with an annual input to the atmosphere of nearly 100 megatons; the product of methane-formation is methane with an annual input to the atmosphere on the order of 500 megatons. Both values are greatly diminished because most of the indicated gases are oxidized by strictly specific microflora of sulphur bacteria and methylotrophes, and do not enter the atmosphere.

Moreover, oxidation of hydrogen is exercised by various hydrogen bacteria forming water as the end product of their catabolism. These bacteria are capable of extracting hydrogen from the atmosphere even at low concentrations. On the other hand, hydrogen bacteria are capable of utilizing negligible concentrations of oxygen. The ecosystem within which hydrogen bacteria play the role of primary producer corresponds well with the hypothetical original atmosphere of the Earth. In the future, these organisms, which produce up to 50 g/l of dry biomass, might be the most advantageous source of protein for mankind, if a cheap

technique of hydrogen extraction is found. Unlike photosynthetic systems, there is no necessity, in this case, to make use of the illuminated surface of the Earth for growing farm plants which is the process that creates the greatest disruption of equilibrium in the biosphere.

The most characteristic technogenic pollutant among the combustible gases was considered carbon monoxide; however, recent isotope determination has shown that there is another natural source with a capacity surpassing the technical output 20-fold. It is supposed to be the decomposition of chlorophyll. The means of removing CO from the atmosphere remained unclear. The laboratory of one of the authors described recently a group of carboxide bacteria which perform CO oxidation according to the equation:

$$25\ CO + 12\ O_2 + H_2O = 24\ CO_2 + (CH_2O).$$

For some carboxide bacteria, the atmosphere with 80% CO is optimal. Thus, the means of removing this gas is also controlled by bacteria (Mishustin and Pertsovskaya 1954).

Summing up, it may be stated that the microcomponents of the atmosphere are influenced by specific microorganisms which mostly belong to litotrophic ones whose detailed description has been given recently by Zavarzin (1972). Bacteria alone, of all living organisms, possess the necessary functions. The components of the two most active photochemcial cycles in the atmosphere--methane and nitrous oxide are bacteria-produced. The supposed original composition of the atmosphere could have been altered by bacteria of precambrian ecosystems towards the contemporary qualitative composition.

The atmosphere is the most common component of the biosphere for all living organisms; changes in its composition are transferred throughout the Earth very quickly.

The atmosphere in which man orginiated as a biological species corresponds to protected parts of the biosphere untouched by man's activity; biosphere reserves are the example.

The atmosphere is in a state of kinetic equilibrium with soil air which is formed mostly by microorganism activity.

The comparison of components of the atmosphere with the operation of specific physiological groups of microorganisms indicates that the concentration of these components is under the influence of definite procaryotes which, alone from all living organisms, possess the appropriate enzymatic activity.

Taking into consideration the length of time that an exclusively procariotic ecosystem has existed on Earth, one may suppose, with considerable conviction, that the Earth's atmosphere was formed greatly due to the activity of bacteria.

It follows that microbiological studies in biosphere reserves are indispensable and should occupy a respectable place in the general program of observation.

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Population Genetic Aspects of Biosphere Reserves

by

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The idea of biosphere reserves as life reserves under natural environmental conditions, which change abruptly, is closely related to the concepts and approaches of a number of biological subjects including population genetics. Genetic approach is of great importance since though the biosphere as a whole undergoes anthropogenic effect today, the results will be realized in changes in the populations--elementary self-reproducing biological units. These populations make up the structure of species included in the ecosystems; thus, the problem of preservation of the available biological communities, and those which are to be brought into being, finally comes down to finding the means to form and stablilize the genetic structure of the population. For this purpose one should have a precise idea of factors of evolution and those internal autoregulation mechanisms which allow them to be steadily reproduced in future generations maintaining balance with the natural environment.

FACTORS AND CONDITIONS OF GENETIC POPULATION STABILITY

Principals of Approach

Population genetics investigate the regularities of conservation and transformation of genetic structure of populations in time and space. The theoretical basis of such a consideration is the well-known Hardy's Law, which describes the fate of genetic information in case of panmixia with an unlimited number outside the habitat. In such a nonstructural community, the genotype proportions and, consequently, gene frequencies approach a steady state in the next generation following the one with panmixia, and remain unchanged in an indefinitely long population succession (fig. 1).

But, such ideal populations practically never occur in nature, since their steady state and stability are disturbed by natural factors. For example, as a result of natural selection, some genotypes will leave more descendants than others, and this will cause a change in the genetic structure of the population. Mutation and gene migration are possible, and the population will also change its genetic characteristic. In addition, accidental genetic drift can take place when population numbers suddenly decrease and an erroneous gene transfer to the next generation is observed.

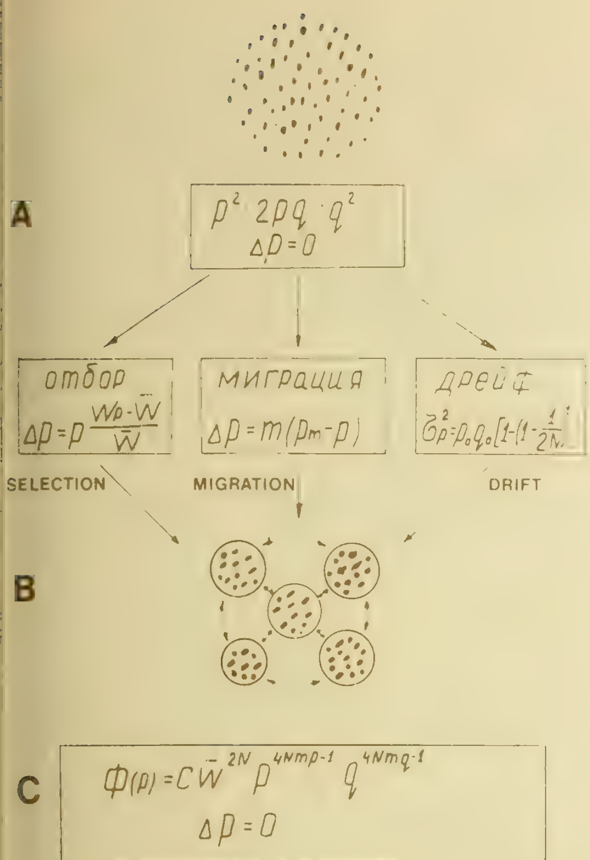

Figure 1.—Basic Mathematical Model for Population Genetics. A. Panmitic population of unlimited size, remaining stable (p = 0) in the absence of selection (w), migration (m) and random gene drift (N)—the so-called Hardy-Weinberg law, represented by the formula I, where p and q = frequency of genes combining at random in homozygote (p^2 and q^2) and heterozygote (pq) gene types; II, III, IV = elementary formulas for selection, migration and drift, as basic factors in gene frequency changes (p); B. Subdivided population, formed as a result of simultaneous effect on gene structure of selection, migration, and random drift; C. Mathematical function for frequency distribution of genes in such a population.

All these factors can be assumed to affect the population simultaneously, so its internal structure could become complicated. The panmictic population will be divided into an aggregate of subpopulations united by a certain degree of interaction. The gene frequencies distribution in such a subdivided population will again become stable and stationary, as a result of equilibrium of centrifugal and centripetal trends. These are the so-called microevolution processes described, in broad terms, in the theory of population genetics.

The principal mathematical models of population genetics were developed in the thirties and forties (S. Wright 1931, Dubinin 1931, Dubinin and Romashov 1932, see also Dubinin 1966, Fisher 1930, Haldane 1932), but their application in practice presupposes observance of at least two main conditions. First, genes should be analyzed as elementary units of heredity, and second, their distribution should be investigated in populations which have been sufficiently characterized as integral biological units.

Though outwardly the formulated requirements seem rather simple, it is not so easy to satisfy them. Indeed, gene frequency is a principal population genetic parameter, but it can be characteristic of a population only when the gene has a distinctly pronounced phenotypic effect. For example, if individual

peculiarities of animal coloration are controlled by allele genes, this leads to several hereditary morphs, differing in said above characteristics. Such a variability is called genetic polymorphism and can be easily investigated. But many species have no polymorphism, are outwardly uniform, their genes are hidden from the observer, and consequently, a direct population-genetic analysis is impossible. That is why until recently the genetics of natural populations was restricted to a small number of outwardly polymorphic species. Only in the last decade, due to success in immunologic and biochemical genetics, have considerable changes taken place. A system of allele genes, coding the synthesis of blood group and various proteins of enzyme and nonenzyme nature, have been discovered in a number of species. This "hidden" hereditary variability is discovered either by immunological reactions or electrophoretic methods. For example, the hereditary electrophoretic variants of enzymes of lactatdehydrohenese and phosphoglucomutase have been described for Pacific salmon *Oncorhynchus nerka* Walb by American and Soviet investigators (Hodgins and Utter 1969, Utter and Hodgins 1970, Altuckhov 1974) by means of field techniques of protein electrophoresis in starch and acrylamid gels. The discovery of broad biochemical hereditary variability of natural populations gave a new, previously unknown, possibility for their comparative investigation; and this today is becoming a central direction in population genetic studies (fig. 2). The following important condition is connected with the choice of the object of investigation. Any biological branch has its own research subject: molecule, cell or individual. Among cytologists, anatomists, or physiologists there is no disagreement on reality and integrity of their investigated levels. But when we turn to ecology or population genetics we do not find such unity--one can count more than 10 terms used to designate intraspecific categories in animals and plants: "population", "Mendelian population", "deme", "ecotype", "morph", "microtopographic race", etc.

A universal terminology, which does not allow ambiguous interpretation, is the index of maturity of any branch of science. It is evident that it does not pertain to population biology since it is still undergoing the analytical stage of development, reflecting the separate interests of morphology, taxonomy, ecology and other biological branches that are much interested in populati[on] levels of life organization. At the same time, it becomes more evident that variability of terminology points to some fundamental peculiarities of the population level which are unfortunate[ly] not always taken into account. First and foremost is the variabili[ty] of the level caused by its internal characteristic principle of hierarchical construction. Only when this circumstance is taken into account will a comparative population-genetic investigation [will] be possible. Further, we shall examine basic results obtained by incorporating such an approach into the study of isolated natural populations.
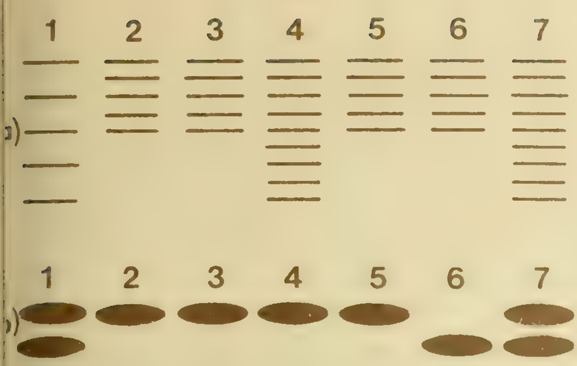
Figure 2.—Hereditary electrophoretic variations of the enzymes lactodehydrogenese (a) and phosphoglucomutase (b) in the Pacific salmon *Oncorhynehus nerka*. a-4-7-heterozygotes, 2, 3, 5, 6-homozygotes of one type, 1-homozygote of another type (electrophoresis in acrylamido gel); b-1 and 7-heterozygotes, 2, 3-6-homozygotes (electrophoresis in starch gelatin).

ATURAL POPULATIONS AS HISTORICALLY ESTABLISHED ENETICALLY STABLE POPULATION SYSTEMS

The most complete data available are for economically valuable pecies of fish, under investigation since 1962 at the biological aculty of Moscow University, in the Institute of General Genetics, .S.S.R. Academy of Sciences, and in the Institute of Marine iology-Far East Scientific Center, U.S.S.R. Academy of Sciences. opulations (so-called local stocks) existing within natural solating borders, formed at least thousands of years ago and escribed in detail biologically, were chosen as investigation bjects.

Under field conditions, we studied various gene markers (blood roup and protein) of tens of thousands of fish caught in self-aintaining native populations--not yet destroyed by fishing or ther external effects. These populations included: sea perch *ebastes mentella* Travin in the northwest Atlantic, European nchovy *Engraulis encrasicholus* in the Black Sea and the sea of zov, red salmon (nerka) in one of the lakes of Kamchatka and akhalin salmon (*Oncorhynchus keta* Walb.) still surviving in opulations artificially maintained for several generations at ish-rearing plants. Let us consider the most important results f these works, taking as an example the sea perch stock, located ear Newfoundland, and an isolated population of nerka.

Newfoundland is shown in figure 3. On the right hand is a ontinental slope where perch concentrates. This slope is a ontinuous line hidden by a thick layer of sea water. Individual oints indicate the location of trawling stations. The expedition essel trawls continuously from top to bottom; and fish from each atch are selected for classification according to both hereditary eculiarities and biological characteristics, such as body length, ex, age, and stage of maturity. The hereditary heterogeneity of he stock can be illustrated on a so-called genogeographical map fig. 4). We see fields of various gene frequencies or concen-rations. This points indirectly to the fact that the school[1] nvestigated can be differentiated into smaller ones which differ

[1] School can probably better be translated as "stock" here and elsewhere in this rticle.

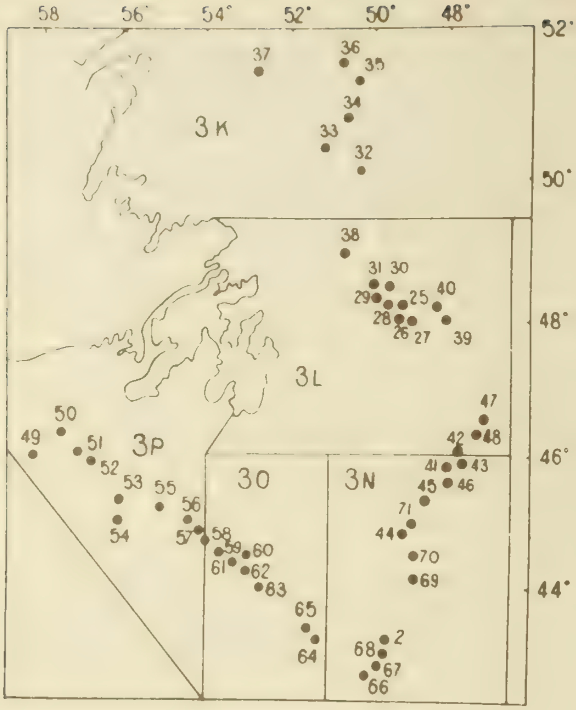

Figure 3.—Chart of Trawling Stations in the Newfoundland Sea Perch *(Sebastes mentella)* Area.

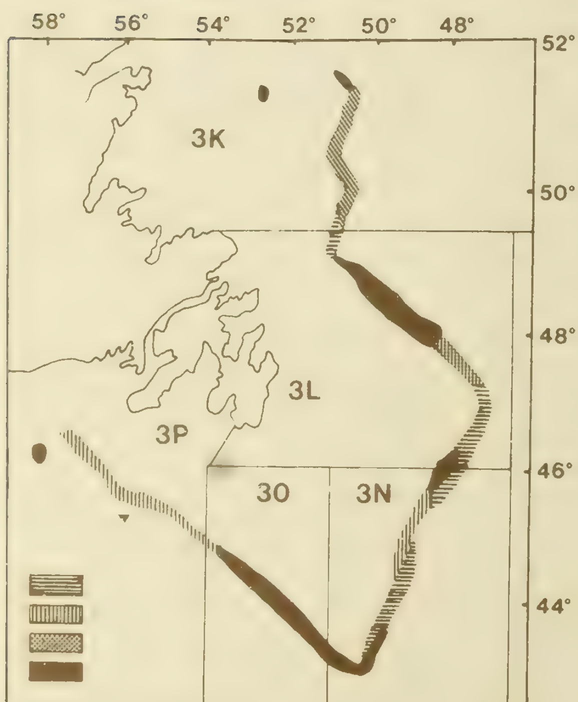

Figure 4.—Gene-geographical map, demon- strating hereditary heterogeneity of th school. The streak shows the geographica difference in the frequency of encounter with gene-carrier fish, coding a specifi blood type: 1-0.35-0.50; 2-0.50-0.65; 3-0.65 0.80; 4-0.85-0.95.

rom a genetic point of view. Indeed, if we analyze the variability of the above-mentioned biological characteristics, we can detect within the school an aggregate of biologically homogeneous, but at the same time, differing groups. These are the so-called elementary populations, each characterized by a specific gene pool Altukhov et al. 1969 a,b).

A population structure of a local school of one species of Pacific salmon - nerka which reproduces itself in Azabach Lake, Kamchatka, is shown in figure 5. The points denote individual spawning areas inhabited by various elementary populations. They can be directly observed, thus there is no need for the labor-consuming work of contouring them.

What is the meaning of such differentiation of a species or a local school? Are they independent populations or parts of a whole such as a school? Ecological observations show that such subpopulations remain as parts of the whole, since none of them covers the whole genetic variation typical to the school; and besides, they interact constantly via gene exchange. Thus, an individual local school is turned into a system of populations connected by interaction. The results of a detailed 4-year investigation of the nerka school at Kamchatka showed a satisfactory agreement with a natural situation of an "island" model for population structure, as suggested by S. Wright (1951). The range of real genetic variability of populations (a histogram) is shown in figure 6 compared with a theoretical distribution of gene frequency (curves). One of the theoretical curves (1) does not evidently correspond to an empirical distribution. In this case

Figure 5.—Locations of separate elementary populations, making up the reproductive structure of the red salmon *(nerka)* of Lake Azabachievo in Kamchatka. The black dots —spawning grounds, where fish were caught immediately after spawning.

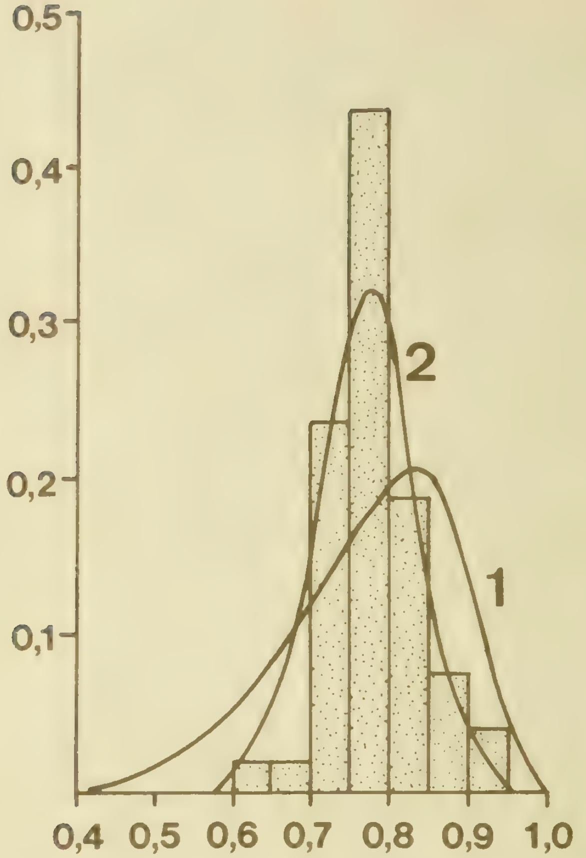

Figure 6.—Actual (histogram) and theoretical (1,2) gene frequency distribution of phosphoglucomutase in the Lake Azabachje red salmon population. 1-with ignoring the factor of selection, 2-with selection pressure. Along the abscissa-gene frequency, along the ordinate—percent of population with the given gene frequency.

the calculations were performed on the assumption that the steady state of the system was set by the balance of migration pressure and an accidental gene drift, caused by a low number of individual subpopulations. The other curve (2) agrees well with empirical data. Here a selection factor is introduced into a model which, as was ascertained, contributes to heterozygous genotypes (Altukhov et al. 1975 a,b).

Thus, in spite of the genetic differentiation of elementary populations, a school, as a whole, remains in equilibrium; and what is of particular importance, this stability reflects its adaptation to a certain natural environment. In the case of environmental shifts which remain within the historically established adaptation optimum, it is this subpopulation variety that serves as a guarantee of the stability of the population system in time and space. If a comparative approach is applied, one will succeed in detecting long-term stability of population systems in time. Despite the variety of their parts, such steady-state genetic processes can be illustrated with several examples.

Figure 7a shows the genetic stability of three successive generations of an Azov anchovy school, differentiated as in other species into elementary populations. The vertical axis denotes gene frequency and the horizontal axis shows samples from in-

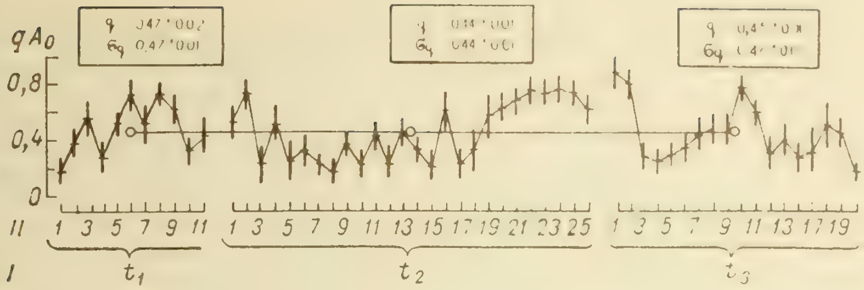

Figure 7a.—The genetic stability of the population of Azov anchovies as a whole, as against the background of variability of separate structural components in subsequent generations t_1, t_2, t_3.

ividual elementary populations which make up a reproductive tructure of the school in three successive generations without verlap. The dashes parallel to the horizontal axis denote the alues of the gene frequencies in the samples and the vertical olumns show 95% confidence intervals. It is clear that in spite f variability in parts, such a subdivided population maintains tself as a whole in the investigated interval.

The second example (fig. 7b) refers to *Drosophila pseudoobscura* hose population genetics were investigated, in particular, by any American authors. Th. Dobzansky investigated the frequency volution of one of the chromosome inversions in California popu- ations. Using the same approach to the subject, one can also how the stability of this population which is usually considered s one undergoing evolutionary transformation. Here the stability f the system has been observed for 70 generations.

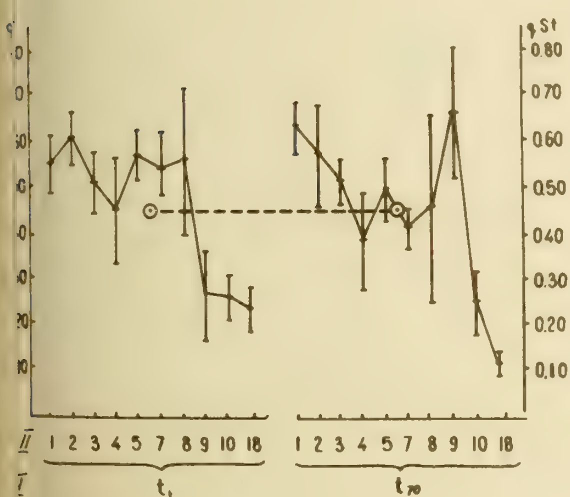

Figure 7b.—Genetic stability of a Drozophyl population in a 70-generation interval, as against the background of variability of separate structural components. According to F. Dobzhanskii's data.

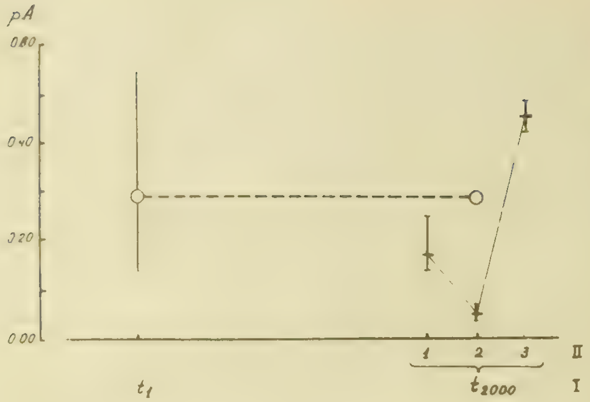

Figure 7c.—Genetic stability of a littorine mollusk population in an interval of 2000 consecutive generations. t_1 = ancient, "pre-population" (total: pA = 0.287 ± 0.028; N = 479), t_{2000} = present populations represented by 3 subpopulations (pA = 0.273 ± 0.01; N = 3818). Vertical axis = gene frequency as basic population-genetics parameter. Horizontal dashes = gene frequency of samples, vertical = 95% confidence intervals, demonstrating the statistical reliability of the data. Circles = average values of gene frequency for the system as a whole.

And as a last example, we'll consider the gastropod *Littorina squalida*, inhabiting a rather isolated lagoon at Busse, Sakhalin. This object is of interest, since its gene effect is "recorded" on the shell surface as a design, which is preserved on the fossil as well. The age of fossil shells was estimated at 5-6 thousand years. This means that the modern population is separated from the ancient one by approximately two thousand successive generations (fig. 7c). Nevertheless, even under changed conditions of the isolated lagoon the population, subdivided into subpopulations, preserved all of its hereditary information.

Thus, the conclusion can be made, that in a definite way planned genetic investigation of natural populations reveals their organization system. This conclusion has both theoretical and principal practical value--if we are indeed discussing a system, then one should consider it as a whole taking into account its internal genetic variation.

CONCLUSIONS

The more complicated the organization of the population system, the more stable it is to various external effects; and consequently one and the same regularity should be observed at any level of biological integration, including species, communities and the biosphere. It is possible to point out that the organizational principles and stability conditions of the biological systems remain universal, that is, *stochastic regulation through the interaction of relatively independent structure components, exchangning information on its own state and that of the natural environment*. Both long term survival of the community in a stable environment and its ability to respond expediently to various external effects, without exceeding its adaptation optimum, are possible only on the basis of maintenance of historically established directions and the intensity of information flow. While planning the means to optimize the interaction between man and the natural environment, the determination of these limits presents an urgent problem; and the investigation of

iological and genetic processes on the basis of biological reserves should promote its practical solution.

The most important problem of optimum relation between anthropogenic and natural landscapes, both in individual regions and ith the biosphere as a whole, ought to be considered from the ame standpoint. Obviously, a situation in which the interelation between natural and anthropogenic landscapes is utually-complementary seems to be correct. By pure intuition, his approach is already used nowdays, for example, in townuilding, but the extent of its quantitative substantiation emains unknown.

Finally, one should emphasize another important aspect of the nvestigation of genetic processes in biosphere reserves. As was lready said, any natural population undergoes the pressure of pontaneous mutation, which changes its genetic structure. Since he frequency of such events is not high (approximately 10^{-5} to 10^{-7} er gene per generation), we did not consider the effect of this actor in this paper. At the same time, the problem of a possible utation rate increase in the populations, due to environmental ollution, is of extreme importance today and is attracting the ttention of many scientists. From that point of view, the organiation of preserved areas and long-term observation of genetic rocesses in native populations can be of great importance for the valuation of rates and directions of mutation processes in related opulations dwelling outside the preserve zones and undergoing orresponding external effects.

In conclusion, the following system of measures, directed owards the optimum interrelation between man and nature on the asis of biosphere reserves as sources of historically established enetic variation, can be outlined:

1. In population genetics terms, the organization of biosphere eserves as representing principal natural zones of the Planet his means conservation of surviving native population systems. he total area and structure of preserve zones should be deterined so as to provide for their stable existence despite external ffects from contiguous anthropogenic landscapes.
2. Biosphere reserves can be used as gene plasma banks to estore the population systems whose internal structure is disurbed as a result of their irrational economic usage or other xtreme external effects. They should also be used to generate ew systems in those natural habitats where historical, geographical nd economic possibilities promote the required conditions for uch measures.
3. Monitoring of genetic processes in biosphere reserves is ndertaken to forecast environmental state and to substantiate the departure point" for evaluation of the rates and direction of the volution of populations and species under the influence of anthropogenic effect, including possible environmental pollution by utagenes.

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The Study of Long-Term Changes in Terrestrial Ecosystems at Biosphere Reserves

by

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Man's influence on the environment, which has presently reached tremendous scope, commenced in remote times. Most likely, as far back as in the neolith, it led to the emergence of the first derivative ecosystems. A question arises in this respect as to what extent the different types of natural biogeocenoses retain their primary structure? The answer to this question is necessary for a proper appraisal of the state of the biosphere and, in particular, for a comprehensive characterization of the standards of the natural environment retained in biosphere reserves. It can be obtained after a thorough examination of the evolution of ecosystems in historical and prehistorical times.

The continuous development of primary and derivative biogeocenoses leads to secular successions, many of which take place notwithstanding human activity. When, however, natural resources are used for economic needs, biogeocenoses are ordinarily regarded as relatively stable ecosystems and their evolutional changes are not taken into consideration. This approach cannot be justified. Our knowledge of Holocene time gives grounds to believe that long-term successions might evoke considerable changes in the ecosystems in time periods commensurable with the life of only several generations of people. At this rate of succession, the study of the evolution of modern biogeocenoses, besides its theoretical interest, acquires serious practical significance. It is necessary for the clarification of general developmental trends and for advance forecasting of the stated Earth's ecosystems.

The study of the history of biogeocenoses incorporates research into the history of individual components of ecosystems, the development of the ecosystem structure and the relationships of ecosystems. Data illustrating the mentioned processes are ordinarily obtained by studying natural deposits of soil, plants or animals. Frequently, the taxonomic composition and the abundance of various species in these deposits are predetermined not so much by the character of ancient associations, as by the conditions of death, accumulation, and conservation of dead organisms. Therefore, their value for paleoecological studies is not the same. Of greatest interest for the study of relationships and the structure of biogeocenoses are peat bogs and lake bottom sediments, cave accumulations of caprolithes and bird food remains.

rcheological relics, and present-day settlements of mammals which ake deep and intricate burrows.

The paleobiological study of peat bogs and lake sediments began long time ago. Its results are the foundation of contemporary otions of the Holocene history. They are well known, and we will ot dwell on the taxonomic peculiarities of this most important ource of information.

Many cave overhangs and niches that have formed in hard rock re places of permanent habitation of animals. The accumulations f excreta and pellets left in those places by birds are, in many ases, quite considerable. The range of fragments of plants, ones, and chitin contained in these excreta, unlike the con-entional tanatocenoses, reflect the functional structure of a art of an ancient ecosystem, parts of which were the hosts of hat shelter. Layer-by-layer taxonomic analysis of that material nd its dating by radiocarbon techniques reveals the gradual lteration of biogeocenoses in the Holocene and at times in the pper Pleistocene. In those cases where geological peculiarities f the locality prevent ground water and atmospheric precipitation rom entering the cave, the composition of the excreta of her-ivores makes it possible to detect the long-term changes in the obility of different chemical elements in the soil-plant system. his opens up the possiility of reconstructing the climatic onditions of the past (Martin et al. 1961).

The chemical analysis of accumulations of excreta in caves can e used for studying the industrial pollution of ecosystems by the eavy metal compounds (Petit and Altenbach 1973).

The burrows of mammals with nest chambers below the alluvial oil horizon are exceptionally interesting paleoecological relics. uch burrows are built by *Alopex*, *Vulpes*, *Meles*, *Hystrix*, *Marmota*, nd some other animals. They are repeatedly reconstructed, ren-ered more complex, and used by many generations of animals. This s accompanied by covering the adjacent sections of ground, remains f vegetation, bones, excreta and food of the hosts, and fragments f skeletons of their tenants and accidental visitors. Present-ay burrows are peculiar burials of parts of an ancient biogeo-enosis. Their study by present-day techniques of paleobotany, aleozoology, paleopedology, and geochronology reveals inter-elated changes in the climate, soil-forming process, the plant over, and the animal population of the surrounding territory Dinesman 1968). The majority of contemporary marmot, badger, and rctic fox burrows originated in the Middle Holocene; approximately 0% exist since the early Holocene. Even older burrows have been ound. One of the oldest badger burrows was recently found in the erman Democratic Republic on terminal moraines in Meklenburg Diebel and Heinrich 1970, Peters et al. 1972). The bones buried n it revealed fragments of the skull of *Citellus* (*Colobotis*) ex gr. *ajor*, which lived in Western Europe in the Pleistocene.

Archeological monuments are similar to old burrows of mammals in the variety of buried biological material. They cover practically all stages of the development of human society and illustrate the natural peculiarities and character of the economic utilization of old ecosystems.

The effectiveness of studying all mentioned burials, in order to form a clear idea of the history of biogeocenoses, is made clear by the case of the steppes of the Russian plain. The study of steppe settlements of *Marmota bobac* and *Citellus pygmaeus* on the watershed meadows and bunchgrass steppes in the district shows that even in early Holocene there were well developed unsalted, but carbonified black soils. The leaching of carbonates from their horizon to the present-day level occurred gradually in the Middle and Late Holocene. This conclusion agrees well with the results of studies in the black soils buried beneath Bronze Age mounds and old fortifications of the Russian State (Modanov et al. 1967). The humus content of the black soil, during late glacier time, underwent comparatively small changes which attests to the shifts in the hydrothermal regimen in the steppe zone.

A characteristic feature of steppes is the humification of a large volume of vegetative remains owing to lavish spring-time humidation of upper soil layers. The humus substances which originated in the dry summer period are either fixed in the form of organo-mineral complexes or mineralized (Tyurin 1949, Aliyev 1966, Aleksandrova 1970, Ponomareva 1974, etc.). The relationship of the carbon of humic acids and non-hydrolized residue and the carbon of humic and fulvic acids depends on the intensity and the direction of the mentioned processes. With the increase in spring humidation and the reduction of the summer desiccation of soil, the hydrolythic decomposition of the vegetable remains increases and the formation of organo-mineral complexes and mineralization of humus substances become less intensive. The relation of humic acids to the non-hydrolized residue becomes broader, the proportion of humic and fulvic acids shifts to the latter, and there is an increase in the volume of the mobile fraction of humus substances.

The study of soil buried by marmots in the Middle Holocene in meadow steppes of the Russian plain has shown that humus formation was characteristic of large volumes of substances of the first fraction and an increased relation of humic acids to the non-hydrolized residue and of humic acids to fulvic acids (fig. 1). The combination of the mentioned signs testifies to intensive humification of vegetable remains, weak oxidation decomposition of humus substances, and the less intensive formation of organo-mineral complexes. The necessary condition for this is the moderate humidation and warmth throughout the spring-summer period.

The humus which was formed in meadow steppes at the beginning of late Holocene is distinguished by a low content of first fraction substances and a narrow relation of humic acids to the non-hydrolized residue and fulvic acids. For arid conditions, this reflects a

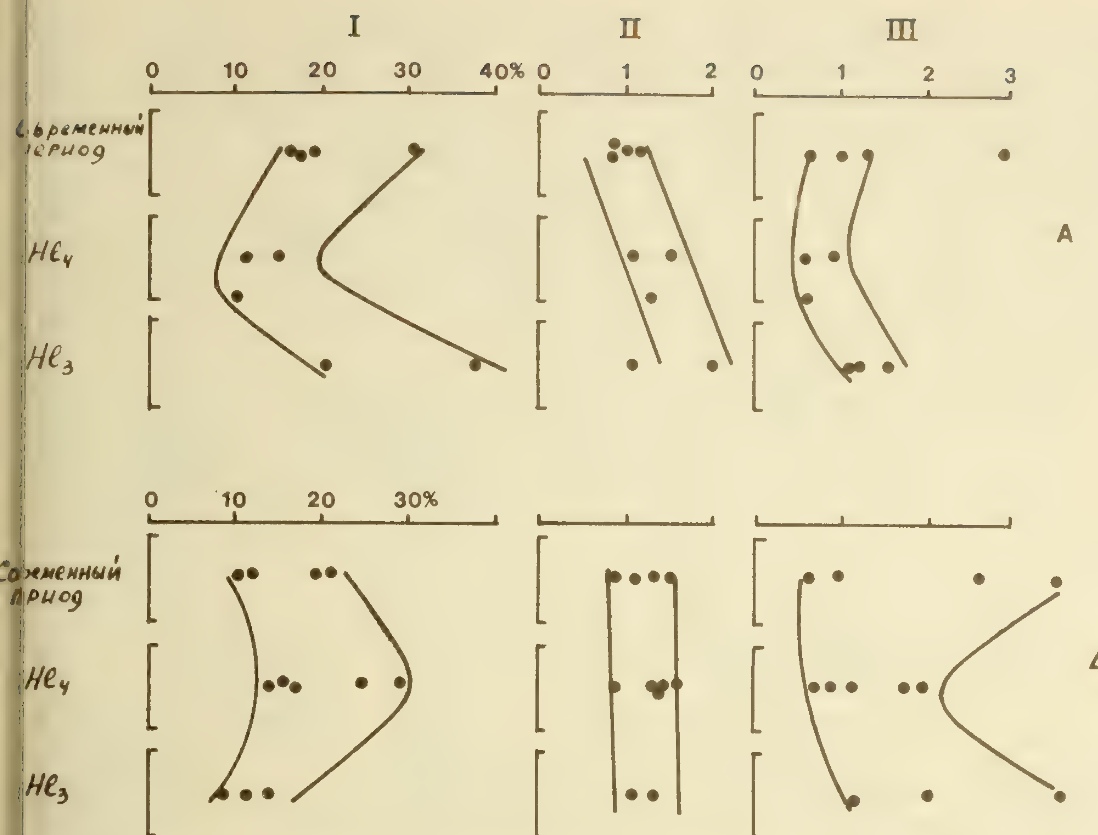

Figure 1.—Change in the humus composition of Holocene chernozyom. a—meadow steppes; b—forb-turf-vinous-cereal steppes. I. first fraction humus acids; II. $C_{h.acids}/C_{f.acids}$; III. $C_{h.acids}/C_{non\text{-}hydrolized\ remains}$.

typical arid condition--weakening of hydrolythic decomposition and humification of plant remains, with an increase in oxidation decomposition of the products.

In contemporary meadow-steppe humus, the number of mobile fractions and the relation of humic acids to the non-hydrolized residue increases again, while the relation of humic acids to fulvo acids decreases. The combination of these characteristics points to the substitution of a humid and moist period for an arid one.

The change in the hydrothermal regimen of the present-day steppes of the Russian plain was different. Judging by the composition of the buried humus, Middle Holocene was distinguished by a moderately warm and dry climate. The beginning of Late Holocene was characterized by increased spring humidation of the humus horizon and its strong and deep desiccation in summer. The contemporary climate of the present-day steppes of the Russian plain is very similar to that in the Middle Holocene.

Judging by the pollen spectrum of the humus horizons, buried by *Marmota* while building their burrows, grass associations prevailed throughout the postglacial period in the southern part of the

Russian plain. As for the relation of the Chenopodiaceae, Compositae, Gramineae and forbs of Early Holocene meadow and the forb-bunchgrass steppes, they were much alike. The taxonomic structure of the grass cover in meadow steppes, which took shape in Early Holocene, remained stable up to the present period. It changed radically in the forb-bunchgrass steppes in the beginning of the Late Holocene judging by a large reduction in the abundance of Compositae. This development lent the pollen spectrums of that type of vegetation its present-day character. Similar changes in the grass cover took place in the bunchgrass steppes of the Black Sea coast (table 1). A number of other peculiarities of the pollen spectrums give us grounds to believe that the reduction in

Table 1--Dominant components of pollen spectrums in the humus layers of the *Marmota bobak* and *Citellus pygmaeus* burrows[1]

Formation time	Meadow	Forb-bunchgrass steppes	Black Sea coastal bunchgrass steppes
Modern	Chenopodiaceae Compositae[2] Forbs	Chenopodiaceae Forbs	Chenopodiaceae Cyperaceae Gramineae Forbs
Beginning of late Holocene	Chenopodiaceae Compositae Forbs	Chenopodiaceae Forbs	
Middle Holocene	Chenopodiaceae Compositae Forbs	Chenopodiaceae Compositae Forbs	*Artemisia* Compositae Gramineae Forbs
Early Holocene	Chenopodiaceae Compositae Forbs	Chenopodiaceae Compositae Forbs	

[1]The dominants of spectrums are the forms where pollen abundance is not less than 15%.

[2]Compositae family includes all forms excepting *Artemisia*.

the abundance of the thistle family in presentday steppes was accompanied by an inhibition of grasses and an increase in the overall xerophytic character of the grass stand. The latter can hardly be explained by climatic conditions in the beginning of the Late Holocene. The humus content shows that there was increased spring humidation in that period and that it predetermined good vegetation of grasses and forbs. It may be noted, however, that the increase in xerophytism and the inhibition of grasses set in when there is pasture degradation of steppe grass stands (Lavrenko 1956). If the cause for the above-mentioned changes in the plant cover was pasture degradation, it had to be accompanied by an

increase in pasture weeds. The first signs of this, however, appear in pollen spectrums only by Middle Holocene. In Late Holocene and in the contemporary period, pasture weeds reach their maximal development. It is noteworthy that this event is preceded by an increase in legumes in the pollen profiles of the meadow and the forb-bunchgrass steppes. This also should be regarded as the result of pasture degradation. In the second stage of degradation, there is widespread development in the creeping plant forms which are poorly digested by cattle (fig. 2); the legume species play a noticeable role among the creeping forms (Kazanskaya 1965).

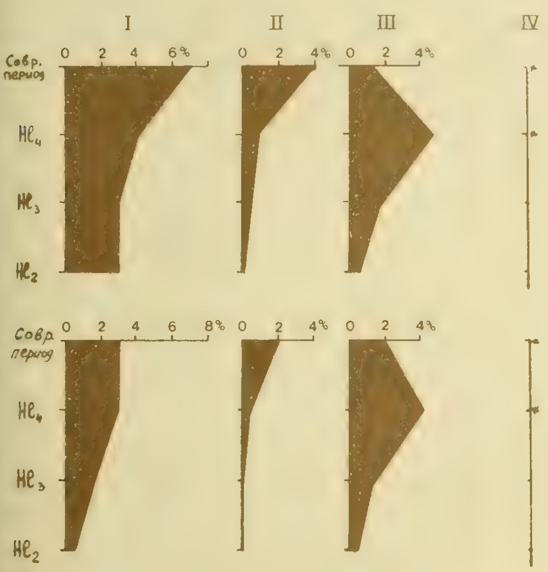

Figure 2.—Change in the amounts of pasture weeds and legumes in SURCHINA palinological spectra. a—meadow steppes; b.—forb-turf-vinous-cereal steppes. I. buckwheat (Polygonaceae); II. plantains (Plantaginaceae); III. legumes (Leguminosa); IV. amaranthaceae.

Judging by the taxonomic composition of bones buried in the burrows of the *Marmota bobak* and *Citellus pygmaeus*, vertebrates in the Early and Middle Holocene on watershed plains of meadow steppes were represented by the species of the steppe faunistic grouping — *Marmota bobak*, *Citellus*, blind rat-mole, common hamster, *Lagurus lagurus*, birch mouse, and the steppe polecat. They have survived without any particular changes to the present time in the virgin lands. The faunistic aspect was gradually changing in the forb-bunchgrass and the bunchgrass steppes, and by this time it has lost its Early Holocene aspect. The analysis of the factors which contributed to that change points to the climatic peculiarities of the post-glacial time and the pasture degradation of the plant cover which commenced in the first half of Late Holocene.

The great volume of pollen of pine and birch in the Early and Middle Holocene spectrums of the steppe marmot burrows (table 2) attest to the wide distribution of these species in ancient meadow and forb-bunchgrass steppes. Real forest biogeocenoses, however, did not exist at the time on the watershed plains. The latter circumstance is confirmed both by the composition of the pollen of grasses (table 1), (fig. 3) and

Table 2--Average pollen spectrums of marmot burrows in the meadow and forb-bunchgrass steppes

Spectrum formation time	Free pollen (percent)	Composition of tree pollen							
		Pine	Birch	Oak	Linden	Elm	Total broad-leaved pollen	Hazel	Alder
		- - - - - - -	- - - -	- - - -	- - - -	Percent	- - - -	- - - -	- - - -
					Meadow steppes				
Modern	22	68	27	4	2	0.5	6.5	7	7
Beginning of Late Holocene	18	82	14	1.6	1.2	.8	3.6	4	5
Middle Holocene	38	67	32	2	3.4	.2	5.6	5.5	6.4
Early Holocene	55	51	47	0	1.5	0	1.5	2	2
					Forb-bunchgrass steppes				
Modern	7	79	16	1.3	.3	1.3	2.9	2.4	8
Beginning of Late Holocene	9	78	16	1.3	1.1	.6	3.0	1.4	6
Middle Holocene	26	85	11	.8	2	1.0	3.8	1.2	7
Early Holocene	14	91	6.5	.5	.5	.5	1.5	.5	7

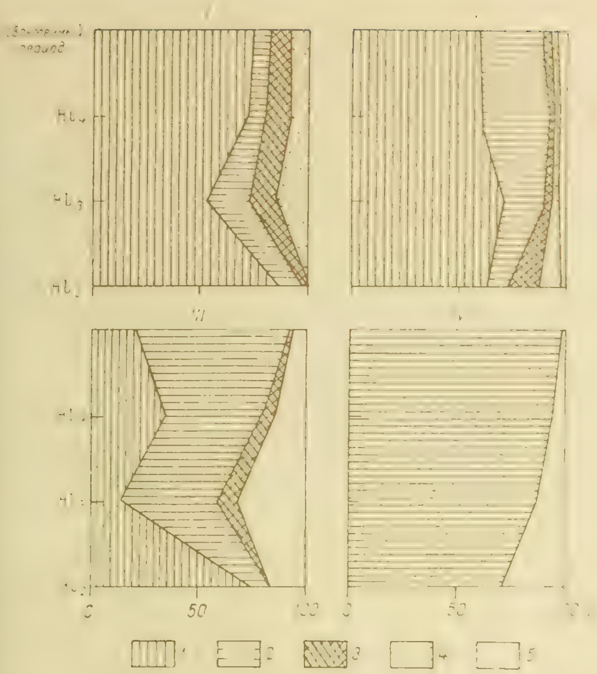

Figure 3.—Change in osteological aspects of steppe faunistic groupings of mammals. I. meadow steppes; II. forb-turf-vinous-cereal steppes; III. turf-vinous-cereal steppes; IV. wormwood-cereal steppes. 1. steppe marmot *(Marmota bobak)*; 2. gophers *(Citellus)*; 3. hamster *(Cricetus Cricetus)*; 4. mole-rat *(Spalax microphtalmus)*; 5. steppe lemming *(Pagurus Pagurus)*.

by the practically complete absence of bones belonging to the species of the forest faunistic grouping in the burrow burials (table 3). They began appearing there, in small numbers, only in the Middle Holocene which coincides in the time with the increase in the abundance of pollen of the broadleaved species in burrow horizons.

The information in table 3 demonstrates that the Middle Holocene maximum content of broadleaved species' pollen in burrow horizons is much weaker than in the low peat bog of the steppe zone. This proves that the real forest biogeocenosis in the Middle Holocene did not reach beyond steppe river valleys. Their spread is confirmed by the abundance of forest items in the food of great

Table 3--Bones of secondary hosts and accidental visitors in burrows of steppe marmots

Bones of mammals	Time of bone burying			
	Early Holocene	Middle Holocene	Late Holocene	Modern time
Total including (%)	16	48	61	50
Steppe species	100	70	50	50
Forest species	0	7	16	24
Desert species	0	19	29	24
Widespread species	0	4	5	2

horned owls which nested along the beach cliffs. This has been established by A. V. Tattar (1958) during the study of cave deposits of the Upper Don.

The unfavorable climate in the beginning of Late Holocene did not alter the formation of forest biogeocenoses in river valleys. This is attested to by the abundance of species of the forest faunistic grouping in the food of the great horned owls which made their nests in river bank cliffs (Tattar 1958) and the increased frequency of the burials of its representatives in the burrows of steppe mammals (table 3).

Most likely the general reduction in tree pollen which is noted in the spectrums of the beginning of Late Holocene was the result of forest cuttings by man. An inevitable result of cutting tree stands in the arid climate of that time would be a clearcut trend of linden replacement by oak (table 2).

Forest vegetation in forb-bunchgrass steppes remained practically the same in the second half of Late Holocene. In the meadow steppe zone it reached watershed areas and covered a part of marmot settlements (Dinesman 1967). It should be noted that the recent appearance of forest on forest-steppe watersheds was identified by T. A. Serebryannaya and E. O. Ilves (1972, 1973, 1974). It is dated as the beginning of Late Holocene. Much earlier V. I. Bibikova (1963) studied osteological materials of archeological monuments of the Ukraine and concluded that the forest steppe of the Russian plain appeared only in Late Holocene on previously forest-free areas. It is easily seen that the results of studying the settlements of mammals, cave deposits, and peat bogs supplement one another and confirm this important conclusion.

The above materials develop trends of natural ecosystems and identify anthropogenic peculiarities in the structure. The approach should be applied to all the main types of the biogeocenotic cover. The historic description of the reference ecosystems of biosphere reserves should be viewed only as the first stage of this work. Owing to the peculiarities of the siting of paleoecological relics, it should be conducted throughout the territories of the regions of which the reserves are representative.

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Remote Sensing in Arid Zone Biosphere Reserve Studies

by

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In our age of computers and spaceships, biosphere resources are being studied using modern technical systems. Remote sensing includes systems which produce valuable information about the landscape features (Kharin 1975). Remote sensors mounted on carriers (aircraft, helicopters, orbital stations, etc.) record reflected (or emitted) electromagnetic waves in different spectral bands. The final information can be obtained in various forms (photograph, photomap, digitized imagery, thematic map, etc.).

Let us first consider the special parameters of remote sensors, then the remote sensing techniques for the study of reserves. Aerial cameras are the main type of applied remote sensors. Aerial photography can be performed in the 270- to 980-nm spectrum band. The main Soviet camera model is the AFA-TE with focal lengths of 55, 70, 100, 140, and 200 mm, and an image size of 18 by 18 cm. There are also long-length cameras. The aerial cameras for desert lands have focal lengths of 100, 140, and 200 cm. Cameras with an image size of 18 by 18 cm and 23 by 23 cm are used in other countries as well as cameras with a small image size.

Various photographic emulsions are used for aerial photography. The panchromatic film sensitive to the visible spectral band is widely used. The infrared is another type of black-and-white film that should be mentioned. Color multi-emulsion films are divided into two types: natural and false color films. One of the latter types, the false color SN-6 film, is used by the Institute of Deserts. This film is used in the German Democratic Republic, Poland, Hungary, and other countries. Similar films in the United States of America are known as "camouflage detection" films.

Photographic systems are the common remote sensors used by investigators of the natural resources. They have a high resolving power; their geometrical properties allow aerial photography to be used for photogrammetric measurements and for compiling thematic maps.

Photographic films have, however, a disadvantage--their wide spectral sensitivity. An alternative method is to obtain the image in narrow spectral bands--multispectral photography. This method uses photographic films and a set of filters which cut off narrow spectral bands. Our investigations have shown that the most suitable zones for multispectral photography are: 400-525 nm

and 600-675 nm in sandy deserts, 600-675 nm and 750-850 nm in landscapes of Turkmenistan, and 400-500 nm and 620-680 nm in the foothills (Kharin 1974). The same result can be obtained by use of scanning systems.

As for the other types of remote sensors, mention should be made here of the infrared scanning systems. They register electromagnetic waves in atmospheric "infrared windows" (1.0-5.3 mkm and 7.0-14.0 mkm). Infrared thermography can be applied to the study of microclimatic phenomena, soil salinization processes in arid lands, and other problems.

The Institute of Deserts has carried out investigations on integrated mapping of the Badkhyz Reserve territory in Turkmenistan. The project has included spectral reflectance investigations, phenological observations, and thematic mapping. Based on these data and a survey of the literature, I propose a program of remote sensing for the study of the arid lands' reserves.

Table 1 lists a number of tasks which should be solved by remote sensing techniques. The main parameters of sensing devices are given as well. Let us consider them in detail.

1. *Compiling thematic maps.* These maps are needed for the normal functioning of reserves and they should cover the whole territory. The range of these maps should cover vegetation, landscape, geomorphology, and forest. Other types of maps, which are not mentioned here, should be compiled based on local conditions and needs.

Thematic maps should be compiled in scales of 1:10,000 to 1:25,000 with the same base map and projections. Map compilation must be performed using coordinated and mutually agreed methodological principles at the same time and scale. Fragments of two thematic maps of Kadkhyz Reserve area are shown in figures 1 and 2. One can see that the outlines of cartographic units (plant and soil association) coincide in many places, supporting the idea that *Pistacia vera* communities are confined to specific ecological conditions.

A set of thematic maps covering the territory of arid lands' reserves will provide investigators with very valuable information about natural conditions, areas, and spatial distribution of landscapes, degree of human influence, the influence of adjacent areas, etc.

2. *Studying the structure and biological productivity of biogeocenoses.* Aerial photographs covering large test areas in reserves should be used for this purpose. Large scale maps must be compiled for these areas.

Photographs at a scale of 1:2,000 and greater convey the image of all trees and shrubs, and large plants of other life forms are pictured as well. Some of the elements of plant cover can be

Table 1--Remote sensing for studying environmental conditions in reserves

Tasks	Carrier	Type of sensing					Scale
		Aerial photography			Multi-spectral scanning	Infrared thermo-graphy	
		Panchro-matic	Infrared	False color			
Compiling thematic maps	Aircraft	+	+	+	+		1:10,000-1:25,000
Studying the structure and productivity of biogeocenoses	Aircraft	+	+	+			1:2,000-1:5,000
Investigating microclimate	Aircraft				+	+	1:25,000
Studying the dymanics of natural phenomena	Space platform				+	+	1:500,000-1:1,000,000
Studying wildlife habitats	Aircraft	+				+	1:10,000-1:2,000
Studying the desertification process	Space platform				+	+	1:500,000-1:1,000,000
Investigating plant phenology	Space platform, aircraft	+	+	+			1:2[illegible],000
Preparing photo-interpretation keys	Aircraft	+					1:10,000-1:2[illegible],000
Visual reconnaissance (combined with selective aerial photography)	Aircraft, helicopter	+					1:1,000-1:[illegible],000

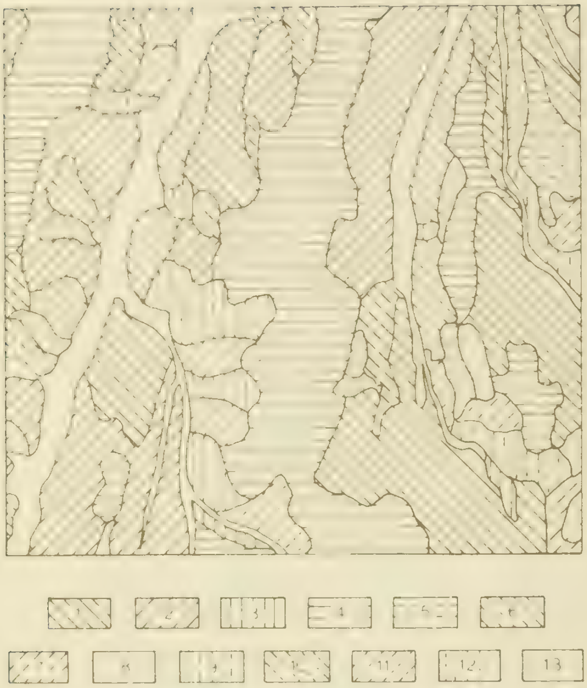

Figure 1.—Fragment of a soil map of the Badkhyz Reserve. 1, 2, 3, 4—Typical serozem soils on loess loam, confined to slopes of different exposition; 5, 6, 7, 8—serozem soils with weakly developed horizons, underlaid by sandstone, confined to slopes of different exposition; 9—abrupt sandstone slopes; 10, 11—weakly developed serozem soils underlaid by marl; 12—talus; 13—typical alluvial serozem soil.

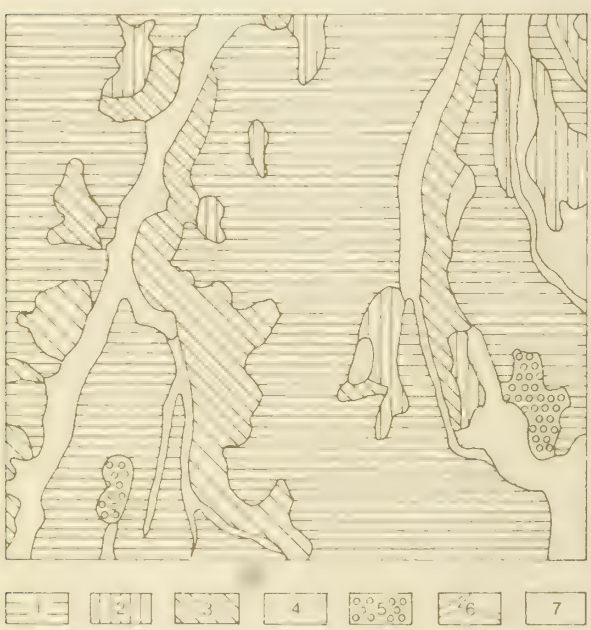

Figure 2.—Fragment of a vegetation map of the Badkhyz Reserve. 1—*Pistacia vera-Artemisia scoparia-Astragalus barrowianus;* 2—*Pistacia vera-Astragalus barrowianus-Onobrychis pulchella-Malcolmia turkestanica;* 3—*Pistacia vera-Cousinia congesta-Ferula badrakema;* 4—*Pistacia vera-Cousinia congesta;* 5—*Pistacia vera-Artemisia scoparia;* 6—*Pistacia vera-Onobrichis pulchella-Cousinia schistoptera;* 7—*Pistacia vera-Fremostachys labiosa-Cousinia schistoptera-Delphinium semibarbatum.*

measured on these photographs (height, crown diameter, density), others can be estimated by the regression technique. In this case the nonpictured elements are estimated from correlative dependencies with pictured elements. In this way the productivity of plant communities can be estimated.

Table 2 shows the relation between crown diameter of *Pistacia vera* (in meters) and the total volume of trees (in cubic decimeters) Crown diameter can be measured on aerial photos.

Table 2--Relation between crown diameter of *Pistacia vera* (DK) and total tree volume (V)

DK	V	DK	V
m	dm^3	m	dm^3
0.5	2.9	4.5	100
1.0	4.0	5.0	150
1.5	7.2	5.5	200
2.0	12.4	6.0	250
2.5	19.7	6.5	300
3.0	29.1	7.0	350
3.5	40.6	8.0	450
4.0	5.0	8.5	500

3. *Investigating microclimates.* In the study of bioclimatic features of a reserve territory, aircraft thermal imagery is useful. Murtha (1972) emphasized that the thermal image allows us to detect frost pockets and microclimatic features related to topography, moisture content, and other factors.

4. *Studying the dynamics of natural phenomena.* Periodic imagery from orbital stations and spaceships may yield valuable information on changes in vegetation cover, soil salinization, riverbeds, and wind and water erosion, etc. Depending on the intensity of these processes, the interval between surveys will vary from 5 to 10 years.

5. *Studying wildlife habitats.* Wild animals sometimes disturb the balance in nature, propagating themselves in great numbers on a reserve territory. Accordingly, current information on species composition, number of animals, forage, migration, etc., must be available to the reserve administration.

Direct counting of animals is performed on large scale serial photographs. Two methods are in practice: manual and automated counting. The latter technique is described by Bajzak (1974) for a waterfowl census. There are three stages: aerial photography, digitization of photographic images, and automated identification of number, species, and age of birds.

Aerial photographs of the scale of 1:10,000 permit us to study forage vegetation and disturbance, and drying up of plants. We can obtain information on forage yield.

Aerial photographs afford the possibility of compiling maps of vegetation damage caused by animals and insects and of estimating

their range by the disturbance they cause in the environment. Driscoll and Watson (1974) investigated, on large scale photographs, the range of dissemination of the pocket gopher (*Thomomys talpoides*), a small animal that may reduce herbage yields by 20% in some parts of North America.

6. *Studying the desertification process.* Desertification is taking place in many arid regions of the world. This process is a result of change in climatic factors in connection with man's activity which disturbs the balance of natural elements.

Remote sensing permits us to study this process on a global scale and at the regional level. Space photos are useful for the study of desertification. Otterman (1974) published interesting information about desertification in the Sinai and Negev deserts. He used images obtained by the American satellite ERTS-1. Areas covered with desert vegetation contrasted with those devoid of vegetation. Areas without vegetation cover were "thermal depressions" with a cooler surface. The rate of precipitation was lower here resulting in desertification. The process was of a cyclic character.

Regional changes in natural conditions can be detected on aerial photos of different scales. Usually, any change in the landscape's appearance, resulting in an optical contrast with the surrounding terrain, is pictured in the photos of a given scale.

7. *Investigating plant phenology.* Phenology of plants in U.S.S.R. reserves is observed made regularly, and calendars of seasonal events are being compiled. These data are of great scientific and practical importance. The three main directions in phenological investigations should be mentioned.

(a) *Systematic observations.* The Institute of Deserts has elaborated a method of phenological observations known as "mathematical phenology." As a result of observations, a phenological distribution series is obtained; this set of observations can be analyzed by standard statistical methods. As an example of this technique, table 3 shows the results of spring phenological observations in the Badkhyz Reserve in 1973 (Kharin and Kiriltseva 1975).

(b) *Phenological mapping.* Using mathematical phenology and false-color photographs, we compiled a set of phenological maps which cover the territory of the Badkhyz Reserve. A fragment of such a map (of *Pistacia vera* phenology) is given in figure 3. The map covers the same area shown in figures 1 and 2.

(c) *Periodic surveys from aircraft or orbital stations.* Photographs may yield valuable information on seasonal changes in appearance of landscape in arid zone reserves. Compilation of zoophenological maps is also of great interest, but adequate methods for compiling such maps have not yet been developed. Remote sensing techniques offer the possibility of developing this capability in the future.

Table 3--Percent of *P[illegible]* trees in various spring phenological phases in the Badkhyz Reserve in April, 1973

Phenophase	Sample plot	Date							All
		April 5	April 8	April 11	April 14	April 17	April 20	April 23	
Pollen formation (male trees)	1	20	20	12	11	10	8	11	100
	2	0	30	32	25	13	0	0	100
	3	31	28	18	10	13	0	0	100
Leaf bud burst	1	0	18	18	25	12	12	5	100
	2	0	3	9	18	43	20	7	100
	3	0	20	19	17	23	21	0	100
Flower opening (female trees)	1	0	12	13	15	19	22	19	100
	2	0	0	0	20	45	23	12	100
	3	0	6	6	10	58	20	0	100
Coming into leaf	1	0	0	7	16	27	37	13	100
	2	0	0	0	0	15	50	35	100
	3	0	0	0	9	28	45	18	100
Ovary formation	1	0	0	0	5	14	44	37	100
	2	0	0	0	0	10	40	[illegible]	100
	3	0	0	0	0	13	38	39	100

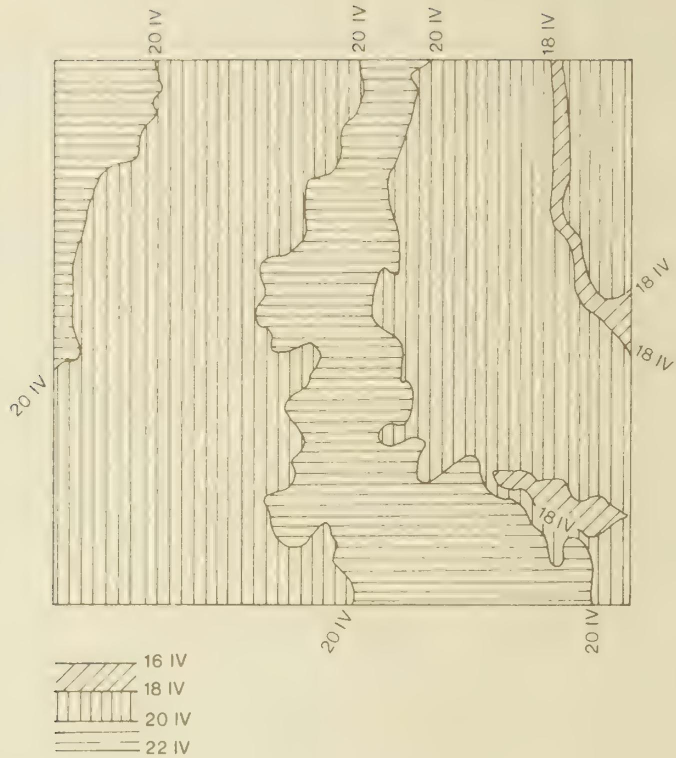

Figure 3.—Phenological map fragment showing percent of *Pistacia vera* coming into leaf on the Badkhyz Reserve.

The frequency with which imagery is obtained in phenological investigations may vary. In the spring it may be 10 to 20 days; in summer, 1 to 2 months. Phenological information in forms a, b, and c, mentioned above, is useful for the normal utilization of arid zone reserves. Maps of phenological events are necessary, for example, for the estimation of forage plant yields, in order to optimize the number of animals, etc.

8. *Preparing photo-interpretation keys.* Reserves and National Parks with typical landscapes and nature monuments should be conserved as virgin lands for future generations. These areas should be photographed from the air, to provide documented evidence of the state of the landscape's appearance. In our opinion, the preparation of a set of reference photographs of these areas is a timely undertaking. These key photographs must be periodically retaken and, together with earlier photographs, kept at reserve offices or at national centers. Modern electronic techniques allow us to keep that information in any suitable form including digitized imagery and electro-magnetic tape recordings.

9. *Visual reconnaissance.* In the daily work of reserve administration, reconnaissance from aircraft or helicopter is a rapid method of obtaining information. In the Badkhyz Reserve,

for example, the administration periodically takes the census of kulan (*Equus hemionus*) and other wild animals by helicopter. By visual reconnaissance we can also accomplish other tasks (phenological observations, fire control, study of wild animal migration, etc.).

It would be very useful for the aerial observer on board a helicopter or aircraft to have a hand-held camera to take pictures of interesting objects and phenomena. The aircraft or helicopter can be equipped with an aerial camera with a small-size image. These pictures can be taken without special equipment.

These, in our opinion, are the main tasks which may be accomplished by investigating natural conditions of reserves using remote sensing. Special funds should be provided for this work, because it would otherwise be impossible to obtain aerial and space imagery. The finanacial problem may be solved in different ways, such as: a. In the framework of international projects, like Earth Resources Technology Satellite (ERTS), Soyuz-Apollo, etc. (In these cases, photographs of reserves will be obtained without allocating special funds.); b. On the basis of National projects, when aircraft or orbital photos may be obtained through small additional funds; c. By allocating special funds for research in reserves. In particular, our work on mapping the Badkhyz Reserve territory was organized using special funds.

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Integrated Studies at the Pushchino Biosphere Station

by

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The establishment of a network of biosphere stations and a global environment monitoring system is one of the finest international collaborations for the sake of man's health and well-being.

The human race is alarmed by the results of its own actions and by the possible consequences of these actions which threaten man's health and well-being. The progress of science and technology has made the anthropogenic factor, by virtue of its end results, comparable to natural factors. Tremendous volumes of industrial waste not only alter the chemical composition of water, atmosphere, and food but materially influence the climate, the circulation of substances and energy in ecosystems, and inhibit biological processes. Nature is no longer capable of coping with the volume of foreign chemical compounds which pollute the atmosphere, water, and soil. We see a noticeable decrease in the self-cleaning ability of the environment. The ecological equilibrium is being disrupted and is becoming unstable.

Mankind is already expending considerable funds to decrease the volume of waste and to diminish the level of environmental pollutio Numerous purification plants are being established as well as closed-cycle industries; their effectiveness, however, is insignificant and they fail to offset the mounting contamination of the biosphere.

Mankind has to admit that it was unprepared for the problem of protecting the environment against anthropogenic contamination. Thus far, there is no conceptualization of the normal state of the biosphere components--quantitative determinations of its background state or of the permissible range in variability; the scope of observation is inadequate. A number of countries have started to monitor environmental quality, but the techniques of collecting and interpreting the resulting data differ greatly from country to country and, for all practical purposes, lack comparability. The task of protecting the biosphere, however, has transcended the national framework, since migrational processes and the concentration and detoxication of biosphere pollutants are developments of a global character. Effective control of biosphere pollution is unthinkable without pooling world resources.

The need for objective information about the level of contamination of the biosphere as a whole gave rise to the idea of

establishing an international network of monitoring stations on the state of biosphere components. The stations should use the same techniques and their concurrent work should produce integrated information on the level of contamination in background locales which are comparatively remote from sources of intensive contamination.

The idea of natural zonality has been taken as the basis for siting the stations over the world's surface, since every natural zone is governed by its own laws of the circulation of substances and energy. The stations should be located in areas with economies typical for the given zone and typical utilization of natural resources.

The tasks of biopshere stations should not be confined merely to observation over the contamination level. Another important function should be research and experimentation on distributal patterns of contaminants, their concentration and detoxication at various points in the ecosystem, biotic responses of the biota to different contaminants, identification of pollutant indicator organisms, etc.

An objective analysis and appraisal of the findings assumes the ablity to distinguish changes in the biosphere taking place in the process of evolution from changes produced by anthropogenic influences. The objects of observation at biosphere stations, therefore, should be not only natural ecosystems uninfluenced by man (reserves) but also ecosystems undergoing different stages of economic development. Therefore, the selection of sites for biosphere stations should be based on the idea of having a sufficiently large area capable of encompassing, within the given natural zone, at least three types of territories: (1) a territory free of economic utilization and, to preserve the gene pool, protected against man's intervention--the Reserve territory; (2) a territory with a typical natural landscape subject to man's minor influence; (3) a territory which has been intensively exploited by agriculture or forestry, e.g., cultivated landscapes. The territories which are intensively used by industry, construction, etc. belong to the sphere of impact monitoring (local monitoring).

The Pushchino Biosphere Station is being established in a typical Central Russian landscape. It is using the facilities of the Biological Research Centre of the U.S.S.R. Academy of Sciences in Pushchino (Moscow region). The plan is to arrange observation points on the territory of four land-users: (1) the Prioksko-Terrace State Reserve: (2) the "Russky Les" experimental-production forest economy association, whose facilities will be used to establish the national park of Central Russia; (3) the fields of the "Bolshevik" state farm which is a pesticide testing center; and, (4) the territory of the experimental field station of the Institute of Agrochemistry and Soil Science of the U.S.S.R. Academy of Sciences - a place of expermentation on melioration and agrochemistry.

The overall station territory will comprise approximately 100 000 hectares, most of it in natural forest tracts. The area of the Prioksko-Terrace Reserve is fully withdrawn from economic utilization. The minimum of forest management measures (selective and sanitary cuttings) is conducted in the forest tracts of the "Russky Les" association. Experimental application of fertilizers, pesticides, and irrigation is conducted on the fields of the experimental field station of the Institute of Agrochemistry and Soil Science of the U.S.S.R. Academy of Sciences and at the "Bolshevik" state farm.

Thus, we are in a position to carry out observation over the background state of natural ecosystems and follow the changes caused by anthropogenic influences. Besides, this, we shall study small town influences on the environment (Pushchino and Serpukhov). Large cities and industrial centers - Moscow, Vladimir, Riazan, Tula, Kaluga - are all more than 100 km away. The Oka River, which flows across the relevant territory, has not been regulated and therefore is conducive to hydrological and hydrochemical studies on a comparatively large waterway.

A number of biological objects (flora and fauna) have been observed for 20 years on the territory of the Prioksko-Terrace Reserve. The identification of lime sequences of nature development is extremely valuable. No less important is the fact that the zones of grey forest soils and sod-podzolic soils have analogs in other countries, which makes it possible to compare the results on the background state of biosphere components at several stations.

The methodology of monitoring at a biosphere station should be based on an integrated biogeocenological approach to the study of natural objects in their entity and relationships. We have done this via our research thanks to the efforts of the distinguished Russian scientists V. I. Vernadsky, B. B. Polynov, and V. N. Sukachev.

In our opinion, the main tasks in starting a biosphere station are: (1) selection of the sites for observation points (biosphere pickets) and organizing the territory; (2) codification of biosphere pickets, collection of information on the initial state of the component of the biogeocenosis (zero cycle); (3) collection and consolidation of available data on the past state of the biosphere components on the controlled territory; (4) organization of the monitoring and corresponding analytical studies; (5) identification of storage places and the development of files (subsequently a museum) of dated specimens of native objects collected in the past on the territory of the controlled region; (6) development of computerized techniques of initial data coding, storage, and processing, and; (7) formulation of "biological monitoring" principles.

Naturally, the global monitoring system will actually begin with the establishment of regular, simultaneous observations on carefully selected sites using standard techniques and identical instruments. This will, however, take time. There is still no agreed-upon program of observation. Observation techniques and

instruments differ greatly and, at times, are incomparable even on a national level. There is no uniform system of instruments adequate for the tasks, and there are many theoretical ambiguities

Furthermore, much time will pass between the commencement of system operation and the objective appraisal of its findings. It will take even more time before we shall be in a position to offer a real forecast of changes in the biosphere for a more or less significant time sequence.

Nevertheless, the present situation calls for effective action. The task is set most specifically. To wait for the development and adoption of a uniform technique, invention, adoption, and adequate manufacture of the necessary instruments and automatic systems of observation which satisfy the requirements of the monitoring program is to waste time and indefinitely delay the appraisal of the state of the biosphere and determination of its development trends.

The indicated program can be accelerated under present-day conditions if we take advantage of the following three important factors:

(1) Inasmuch as most of the planned biosphere stations are located in places where different establishments are already conducting integrated studies and there is a definite range of observations in a time sequence, it is necessary to continue the goal-oriented studies using the available resources, ways, and means - namely the state and changes in environment by the largest possible range of parameters, gradually approximating the desired level. We believe that, in this case, the most fruitful direction of research is the balance approach (the balance of organic substances in ecosystems, the balance of biophyllic elements, the hydro and thermal balance, etc.).

The positive significance of these studies at the preparatory stage of the establishment of a global-monitoring system is not only the collection of data on the state of environment, but also the formation and training of groups of different specialists. Such groups are capable of joint-integrated studies and can produce summarized functional information on the relationships of biosphere components. They can also conduct experiments to identify the regularities of migration, concentration, and detoxication of pollutants in the biosphere and in its components.

(2) Numerous cartographic data, texts, and figures on the state of natural components and man's economic activity at different periods of history are scattered in literature and in various archives. The concentration, processing, and tabulation of this information on a regional level might provide necessary data about the changes in the region's nature, resulting from both evolution and anthropogenous influences. Banks of a biosphere station, should be organized mainly along two lines: (a) stages of natural evolution, and; (b) stages of economic development of the region.

(3) There are a large number of natural exhibits (specimens of soil, rock, peat, trees, herbariums, animals, insects, archaeological material, etc.) at regional museums of history and local studies, at museums of schools and research establishments, and in private collections. All of them were collected in definite places at different periods of time. Organization of a regional collection of dated specimens and their subsequent chemical analysis, in chronological order, offers another chance of obtaining a time series aimed at identifying the trends of contamination up to the present time. This work, however, requires considerable effort and resources. Besides this, considerable prudence should be exercised, since this concerns unique exhibits of historical importance. In our region, we have already discovered herbariums, soil specimens, stuffed animals, and collections of insects dating to different periods.

The chemical analysis of natural objects and the quantitative determination of pollutants is not the final research stage. Other important aspects are the reaction of living organisms, their associations and ecosystems as a whole, to the level of specific pollution, the identification of the biological effect of pollution, the identification of organism-indicators of pollution, and determination of types of reaction of different organisms to different pollutants. This is a complex task, especially if we take into consideration the necessity of strictly distinguishing the changes caused by evolution from those by pollution.

The reaction of living animals to environmental changes and to pollution can be evaluated by the changes in the numbers, composition, biomass, physiological functions, migration, activity, life span, and morphology. It happened, for instance, that there has been a considerable drop in the number of ordinary earthworms in our region in recent decades. The causes of this have yet to be determined in the context of the entire program.

For a complete picture of the situation, we should have a full inventory of all sources of contamination of soil, water, and atmosphere in the territory of the region and we should determine the range of the influence of the contaminants.

All this information can be collected and processed before the global-monitoring system is fully launched and even parallel the global-monitoring system in the first years of observation. This "step back into the past" will make it possible for valid forecasting, even in the initial period of the functioning of the system, of possible changes in the biosphere during a definite period of time and elucidate the main development trends caused by man's influence.

The central task during the preparatory period of the organizat of the biosphere station in Pushchino is the establishment of an observation and analytical complex. Many subdivisions of the Institute of Agrochemistry and Soil Science, the associates of the Prioksko-Terrace Reserve, Moscow University, the Hydrometeorological Service, and other concerned establishments have been drawn to this work.

For the first stage, we have chosen five permanent biosphere sites. Three of them are in natural biogeocenoses--an oak wood, a pine wood, a forest glade--two are on agricultural land, e.g., non-irrigated ploughland at a watershed and on irrigated floodland of the Oka River.

Though the studies are conducted concurrently and in an integrated manner, we have subdivided the objects and parameters of studies for greater clarity.

OBJECTS AND PARAMETERS OF OBSERVATION

Objects:

ATMOSPHERE:
(1) elements of the microclimate (radiation, thermal water balance, variations of the climate in time and space);
(2) total contamination of the atmosphere including dust content;
(3) chemical composition of pollutants (dust, liquid and solid atmospheric fallout);
(4) pollution of the atmosphere and photosynthesis;
(5) gases: CO_2, CO, O_2, O_3, SO_2/H_2S, NO_x.

WATER:
(1) rivers, lakes, marshes, temporary streams puddles;
(2) ground water (depth);
(3) soil solutions;

Parameters
(1) water regimen
(2) general contamination
(3) organic substances
(4) biophyllic elements
(5) heavy metal and trace elements
(6) organochlorides (DDT, PCB).

SOILS:
(1) Morphology, chemical composition, physical state;
(2) Soil regimens: (a) moisture, (b) temperature, (c) soil-air composition (CO_2, O_2), (d) salt composition, pH, Eh, Fe, Ca, Mg, (e) organic content, (f) heavy metals, (g) trace elements, (h) absorbed toxicants.
(3) Soil solutions - SO_4, Cl, NO_3, biophyllic elements, heavy metals, trace elements, organic substances.
(4) Humus and its forms.

BIOTA:
(1) Surface and subsurface phytomass; temporal-spatial structure and annual dynamics of its amount and chemical composition; the dependence of photosynthesis upon the extent of atmospheric contamination.
(2) Fauna: dynamics in time and space, activity (specifically of invertebrates).

(3) Microflora: time and space dynamics of the composition, number, and activity.
(4) Farm animals: number, mass, productivity, geographical distribution.

FOOD:
(1) Harvest of farm plants, quality, caloric content, protein content.
(2) Chemical compositon of food of plant and animal origin (extent of contamination).
(3) Analysis of feeds and additional mineral feeds for animals consumed by man.

LOCAL CONDITIONS: Diseases of man, animals, and plants subject to analysis in time and space (life span, population density, number, birth and death rate, etc.).

Besides creating an observation complex for the period, we also plan a series of studies related to establishing a data bank at the biosphere station: (1) the compilation of a regional atlas on "Biosphere Resources"; (2) the compilation of regional catalogue of data characterizing the state of biosphere components at different time periods; (3) the compilation of a data catalogue and an atlas of the region's history of economic development; (4) the compilation of a data catalogue on biotic reactions to changes in the environment and anthropogenic contamination; (5) accidental verification of biota's reaction to the character and level of contamination; (6) the compilation of a catalogue of storage places for dated specimens, collected at different time periods in the region in order to set up a regional collection and provide for subsequent analyses.

In order to fulfill these objectives, the Institute of Agrochemistry and Soil Science of the U.S.S.R. Academy of Sciences established a Division for Ecological-Biosphere Research which incorporates five subdivisions, including: Laboratory of Bioproductivity of Landscapes, Laboratory of Modeling Soil Processes, Laboratory of Migration and Metabolism of Herbicides, a branch of scientific data storage and an independent structural unit - "Biosphere Station".

Besides this, to fulfill the field program the Institute established an ecological-biosphere team which will incorporate the associates from most of the subdivisions of the Institute and from the Prioksko-Terrace Reserve, undergraduates and members of the faculty of Moscow University and of Moscow Forest Industry Institute and personnel from other establishments - an entire contingent of specialists capable of ensuring fulfilment of the entire range of studies stipulated by the program.

Integrated Monitoring of Environmental Pollution at Biosphere Reserves (Organization and Methods)

by

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INTRODUCTION

Man's impact on the environment has increased sharply in recent decades. The volume of gaseous, liquid, and solid waste discharged into the environment has become comparable with the volumes of matter transferred in the course of natural events. The consequences are particularly dangerous when the environment is polluted with substances which are alien to nature and whose natural processing is impossible.

The concentration of pollutants in ambient air, in natural waters, soil, and in the biota (including man) may reach levels where unfavorable changes in the ecosystems or in their components should be expected, including changes in climate.

In order to distinguish anthropogenic changes, against the background of natural processes, special observations should be conducted on the state of the biosphere. The main objective of these investigations should be information about the intial state of the environment, its present level of contamination, paths and rates of global dispersion of pollutants, and directions of change in environmental quality. This information is needed to understand the basic physico-chemical and biological processes and to expand our knowledge about the influence of pollutants on biological systems and the biosphere as a whole. This is necessary in order to draft recommendations for optimal and global environmental control.

A system of biosphere reserves is being established to study, control, and forecast the state of anthropogenic changes in the biosphere. This system should be a component of national monitoring of environmental conditions.

The biosphere reserve system (BRS) presupposes a set of purposeful, systematic observations of environmental elements or indicators of its state; the observations are carried out in keeping with a definite program, employing comparable methodology of collecting and analyzing the data about environment. The network of biosphere reserves should be representative of the main biomes of our planet.

The main tasks which should be resolved by this system, with the help of conventional and new services, are the following: (a) observation of changes in the state of the biosphere and identification of changes caused by man's activity; (b) forecasting and determination of trends in biosphere changes; and (c) appraisal of changes and trends of changes in the biosphere.

The settlement of these tasks will help elaborate recommendations for prevention of undesirable consequences, and optimizing man-environment relationships.

An essential principle of establishing a biosphere reserve system should be ensuring the integrated character of observation including all the main pollutants in all media, all the essential elements of the biosphere, and the accompanying factors which make easier the interpretation of the findings. This integrated approach is particularly suitable for determining and forecasting the overall biosphere condition. Primarily, this relates to the necessity of developing methods of biological monitoring as one of the most essential, but least developed types of monitoring.

The organization of the biosphere reserve system should provide for observations in keeping with a program that incorporates all priority pollutants recommended at the Intergovernmental Council on Monitoring in Nairobi (1974). Some additional pollutants in different media should be included as well as other elements of the environment which might be of interest (at present or in the future) from the point of view of an integrated appraisal of the state of the biosphere.

To identify the trends in biosphere conditions and to develop a forecast, we should have information on the past state of the biosphere. The possibility of new tasks, techniques, and instruments for studying the state of the biosphere makes necessary the development of means of preserving the specimens taken at the present time and techniques of their durable storage.

The present report discusses pollution monitoring programs designed for biosphere reserves in the Soviet Union. The following approach to monitoring refers mainly to dry-land biosphere reserves, although there could be little difficulty in developing a program of observation for marine biosphere reserves. The fact that bodies of water exist within dry-land reserves allows for considerable expansion of a program of observation, making it more comprehensive.

MONITORING THE CHANGES IN THE STATE OF THE BIOSPHERE

The environmental monitoring program should cover three main fields of research:

1. Geophysical parameters of the environment:

(a) measuring solar radiat[illegible] biosphere processes. This ne[illegible] actinometric observation on the terr[illegible], i.e., measuring solar radiation intensity (direct, scattered, and total), the radiation bal[illegible] dicators of dust content in the atmosphere, turbid[illegible] may be obtained by way of [illegible] scattered solar radiation;

(b) identification of the [illegible] anthropogenic origin on biosphere's overall energy by measuring air temperature in time and space (the vertical aspect). These measurements are a component of weather obser[illegible];

(c) meteorological monitoring in the near-the-earth layer (up to 15-20 m) and in the boundary layer (aerological monitoring) to cover temperature and air humidity, wind velocity and direction, atmospheric pressure, longitudinal and vertical components of the wind velocity, pulsation, and atmospheric precipitation;

(d) hydrological observations recording variations in leve[illegible] average rate, and total discharge of rivers, granulometric composition of suspended particles and bottom sediment, river bed processes, etc., i.e., the parameters which describe the water and thermal balances of rivers and other reservoirs and the specific features of their regimen.

The observations listed under points (a) through (d) can be carried out in the framework of national weather services (or the World Meteorological Organization) using standard techniques and equipment and, therefore, do not present any fundamental difficulties. It is possible that the time or frequency of observation will have to be altered to meet the needs of an integrated study of environmental conditions.

2. Observations on the chemical composition (of natural and human orgin) of the atmosphere, precipitation, surface waters, soil, bottom sediments and the biota.

To perform this set of observations, a list of the most important pollutants of anthropogenic origin must first be compiled. The criteria for selecting these priority pollutants include factors such as spread, persistence, possibility of conveyance along alimentary chains and the accumulation in humans, toxicity, and potential for transformation into more dangerous chemical compounds.

The following contaminants should be monitored in accordan[illegible] with these criteria in the observation program on biosph[illegible] reserves:

I. Ambient air
   1. Sulfur dioxide
   2. Suspended particles (aerosols)
   3. Carbon dioxide
   4. Nitrogen oxides (nitric oxide and nitrogen dioxid[illegible]
   5. Ozone
   6. Carbon monoxide

7. Reactive hydrocarbons

8. Lead, mercury, arsenic, and cadmium content of aerosols and, possibly, the content of sodium and chlorine ions.

II. Atmospheric fallout

1. DDT and other chlororganic compounds (PC), lead, mercury arsenic, and cadmium.

2. All anions and cations recommended for determination at WMO observation stations (sulphates, nitrates, chlorides, ions of ammonium, calcium, etc., electroconductivity, pH, and biogenic elements).

III. Water

1. Mercury (including methyl mercury), lead, arsenic, and cadmium.

2. DDT and PCB, biogenic elements.

3. Petroleum products (marine areas).

IV. Soil

1. Mercury, lead, arsenic, cadmium, DDT, and PCB.

V. Biota (agricultural crops, grasses, etc.)

1. Lead, mercury, arsenic, cadmium, DDT, and PCB.

2. Biological monitoring.

Biological monitoring should have an important place in the biological reserve system. To a certain extent, it is represented in the above list by the determination of DDT and other chlororganic compounds and also of metals in farm crops, grasses, and other representatives of the biota.

As for water subjects, it is more expedient to include the studies of hydrobiological indicators in biological monitoring.

It should be emphasized that the important thing is not only to study the accumulation of different pollutants in biological objects but also to identify their biological and ecological effects. Special attention should be drawn to this type of monitoring owing to its importance and scanty information.

It is of interest to preserve special specimens for a long time for their subsequent analysis. The relevant motivation is that in the future we may want to study pollutants which are currently unrecognized or considered unimportant at present. It is also possible that more powerful analytical techniques and instruments will appear in the future making additional analyses desirable. Development of techniques of conserving the specimens for durable storage and the development of banks of such specimens might be another important task of monitoring.

TECHNIQUES AND INSTRUMENTS FOR THE BRS

The main peculiarity in analyzing pollutants in the biosphere reserve system is their extremely low levels in the studied objects

on the one hand, and simultaneous presence in specimens of accompanying pollutants and natural compounds which are liable to interfere with proper analyses on the other hand. Under such circumstances high sensitivity and the specific tests may be achieved in most cases by enriching the specimens and by using more refined physico-chemical techniques and instruments.

It should be noted that the techniques, specifically elaborated for determining background concentrations of pollutants, are nonexistent in many cases. Therefore, a great deal of work will have to be carried out to determine the possibility of using techniques initially designed for testing higher levels of pollution. Development of standard and reference specimens has an important part in ensuring the unity and the correctness of measurements along with comparable international technique and instrument testing.

Sulfur Dioxide

Not one of the presently known standard automatic instruments can be used for determining background concentrations of sulfur dioxide (~ 1 mkg/m^3). In the first stage of observation at biosphere reserves, it will most likely be neccessary to use one of the manual methods recommended by the World Meteorological Organization WMO (for instance, the West-Gaek technique).

Ozone

Background concentrations of ozone may vary from several to 100-200 mkg/m^3; there are automatic gas analyzers for measuring such concentrations. These instruments are constructed on different principles. The best among them is, most likely, the analyzer based on chemoluminescence which develops in ozone - ethylene reactions.

Nitrogen Oxide

Background values of nitrogen dioxide may vary from 0.4 to 10 mkg/m^3, nitric oxides--by less than 6 mkg/m^3; the reliable determination of such low concentrations is not yet completely solved.

Carbon Monoxide

The necessary accuracy of carbon monoxide determinations ($\pm$ 0.2 ppm when the measuring value approximate 320 ppm) may be achieved by automatic analyzers which are based on nondispersion infrared spectrophotometry. Background concentrations of carbon monoxide on the order of 0.1 mg/m^3 may be measured, for instance, by the gas chromatographic technique in which carbon monoxide is reduced to methane (nickel being the catalyst) and recorded in a flame-ionization detector.

Olympic National Park

APPENDIX

THE CAUCASUS BIOSPHERE RESERVE

The reserve is located in the western part of the Caucasus mountain range in the square 39°40' to 40°50' northern latitude and 43°30' to 44°0.5' eastern longitude in the Krasnodar and Stravropol regions of the Russian Soviet Federated Socialist Republic (RSFSR). The yew-box tree grove, district of the settlement Xhost, city Sochi, and the Sochi Forest Park are separated from the basic territory of the reserve. The geography of the reserve varies from the lowlands close to sea level to the mountain peaks of the main Caucasus mountain range at altitudes of 3 360 m. The territory of the reserve is 263 500 ha and consists of a typical mountain landscape. The main Caucasus mountain range and Peredovoj, located to the north of the main range, form the basis of the reserve's relief.

A united reserve territory exists in correspondence with the statute covering the Caucasus State Reserve. A reserve buffer zone is currently being created.

Flora

The flora of the reserve reflects the complex formation history of the present western Caucasus surface and the considerable variation in relief and in climate. The flora includes over 1,500 species of higher plants. The flora probably includes more than 3,000 species if the varieties of mosses, fungi, lichens and algae are added. The number of trees and shrubs--165 species--is large. Endemic plants amount to about 20 percent of the total number. Tertiary relict plants are preserved in the reserve. They are representatives of the ancient preglacial flora of the Caucasus: Caucasus fir (*Abies nordmaniana*), eastern beech (*Fagus orientalis*), chestnut (*Castanea sativa*), eastern spruce (*Picea orientalis*), Iberian oak (*Quercus iberica*), sycamore (*Acer pseudoplatanus*), Caucasus linden tree (*Tilia caucasica*), and others. A large part of the reserve is covered by forests. Broadleaf forests grow up to 1 200 to 1 300 m in the mountain belt. Oak forests can be found on the bright southern aspects at altitudes of 800 to 900 m. Beech forests are common and often cover the entire southern slope of the main range from 500 m up to the upper forest boundary. Fir forests are the main representatives, amounting to about two-thirds

of the entire forest area. Beginning at altitidues of 2 300 to 2 500 m subalpine meadow vegetation gives way to vegetation of the alpine belt; this continues up to 2 800 to 2 900 m above sea level.

Fauna

The fauna of the western Caucasus is completely represented in the reserve by 59 species of mammals and 232 species of birds, of which more than 132 nest. Aurochs (*Carpa caucasica*), chamois (*Rupicarpa rupicarpa*), and wild boar (*Sus scrota*) are very numerous. Roe deer are found in the broadleaf forest belt. In 1940 the reserve began to breed aurochs in the Caucasus. There are currently 900 head in the Caucasus Reserve and neighboring territories.

Human Impact

Man's economic activity has had a minimum impact on natural conditions in the Caucasus Reserve. There was never any logging on its basic territory and a considerable area of the alpine meadows have never been grazed. There are no settlements on the reserve territory.

During its existence, the reserve has inventoried its flora and fauna and studied the biology and ecology of individual (especially rare) species. Since 1976, the reserve has begun the complex task of studying structure and dynamics of the basic ecosystems of the northwestern Caucasus. The territory is open for both expeditionary and stationary research.

Additional Information

References: Works of the Caucasus Reservation (vols. 1-2); Bannikov, A. G., Golgovskaya, K. Yu. Kotov, V. A. The Caucasus Reservation, Publishing House "Knowledge", 1967.

Staff: Full-time reserve staff totals 180.

Budget: The annual reserve budget is 290,000 rubles.

Address: U.S.S.R., 354067, Krasnodar Region, RSFSR, Sochi, Sukhumskoe Shosse, 7-A.

THE BEREZINA BIOSPHERE RESERVE

The Berezina Reserve is located in the White Russian Lake District on the territory of the Vitebsk and Minsk regions, 115 km from Minsk and 140 km from Vitebsk, in the square 54°30' to 55°00' northern latitude and 28°00' to 28°30' eastern longitude. The altitude of the reserve territory is 120 to 250 m above sea level. Its external boundaries encompass 76 201 ha, a protected zone of 33 000 ha.

In 1976 the reserve area was organized into two zones: A nuclear zone of absolute reserve character totalling 34 276 ha or 45 percent of the area and a buffer zone of 41 934 ha or 55 percent of the area.

Flora

In terms of botany and geography the reserve territory is within the subzone of broadleaf and spruce forests of the Russian plain. The forest area is 63 667 ha or 83.6 percent of the total. Thirty forest types are represented in the reserve. Pine, spruce, birch, and black alder forests prevail. There are also forests of oak, ash and linden. The non-forest areas are mainly swamps and meadows of three types. The flora of the reserve includes 698 species of flowers and higher spore-bearing plants which belong to 359 genera and 100 families (excluding mosses). Thirty-eight species of rare and declining plants are found on the reserve. Relics of the glacial period are the dwarf birch, northern *Linnaea borealis* and *Dentaria bulbifera* L.

Fauna

Recorded vertebrates total 295 species which include 52 species of mammals, 197 species of birds (152 nesting, 30 migratory, 6 overwintering, and 9 resident species). There are 5 species of reptiles, 8 of amphibians, and 33 species of fish. The basic and most valued animal species are beaver, elk, wild boar, roe deer, bear, woodgrouse, heathcock, and black and white stork.

Human Impact

The reserve was subject to human impact before its organization. At present the nuclear zone provides a completely protected regime. The ecosystems in the buffer zone are subject to economic use.

Potential for Scientific Studies

From 1961 to 1970 studies of abiotic conditions, the typology of forests and swamps and the hydrologic regime were carried out in the reserve. During 1971 to 1975, studies were directed toward inventorying the natural objects of the reserve and developing measures for the protection and reproduction of the natural resources in the biogeocenoses of the reserve.

The ecology and biology of single species and of basic forest ecosystems was emphasized. The reserve is located close to the Minsk-Vitebsk highway and has a road network for internal use.

Additional Information

References: Works of the Berezina Reservation: The Berezina Reservation. No. 1 (1970), No. 2 (1972); the Reservation on the Berezina, Publishing House "Harvest", Minsk, U.S.S.R. 1974.

Staff: There are presently 270 members of the full-time staff.

Budget: The annual budget of the reserve is 500,000 rubles.

Address: U.S.S.R., 211188, Byelorussian Soviet Socialist Republic, Post Office Domzheritsa, Lepel' District, Vitebsk Region.

THE OKA-TERRACE BIOSPHERE RESERVE

The Oka-Terrace Reserve is located in a valley on the left shore of the Oka River, 12 km to the east of Serpukhov, and 100 km south of Moscow. The reserve and the station are located in the square 54 to 55° northern latitude and 37 to 38° eastern longitude. The elevation of the reserve is 180 to 200 m above sea level with a reserve area of 4 945 ha.

The entire territory of the reserve is strictly protected. Ther are no buffer or other zones. In the northwestern part of the reserve there is an isolated area of 200 ha where a nursery was built for breeding aurochs.

Since 1976, the U.S.S.R. Academy of Sciences Experiment Station of the Institute of Agricultural Chemistry and Soil Science has carried out biosphere observations in collaboration with the reserv There is a regular bus service with Pushchino on the Oka and Serpukhov.

Flora

The Oka-Terrace Reserve is located in the central part of the eastern European plain at the boundary of the broadleaf and mixed forest subzones. The reserve is covered by forests. The main forests are a rich variety of pine forest types. The vegetative cover of the reserve also includes: unique relict meadow-steppe phytocenoses with a large number of steppe and rare mountain species (e.g., *Aconicum authora, Conex obtusata, Dentaria tennifoli* broadleaf forests of oak and linden; spruce forests and sphagnum swamps with elements of taiga flora (e.g., *Andromeda politolia, Oxycoccus quadripetalus,* and *Drosera rotundifolia*); and unusual steppe plants (e.g., *Stipa jeannis, Festuca sulcata, Phleum phleoi Tulipa biebersteiniana, Cerasus fruticosa,* and *Veratum nigrum*) and other species (about 50) which are separated from their basic distributional area by 200 to 400 km.

Fauna

Fifty-three species of mammals and more than 130 species of birds are registered at the reserve. Among the basic species are representatives of broadleaf forests (e.g., [illegible], *Apodemus flavicollis*, and *Discus viridis*); of the taiga zone (e.g., *Tetrao urogallus*, and *Tetrastis bonasia*); of open spaces (*Microtus arvalis*) and others (e.g., *Vulpes vulpes*, *Sorex araneus*, and *Alces alces*). River beaver, roe deer, and wild boar live on the reserve and in neighboring areas. Aurochs are bred under nursery conditions.

Additional Information

References: Works of the Oka-Terrace Reservation: Nos. 1-5 (1957, 1958, 1961, 1961, 1971); a pamphlet "The Oka-Terrace State Reservation," Moscow, 1974 (in Russian and English).

Staff: Full-time staff is presently 70.

Budget: The annual budget of the reserve is 140,000 rubles.

Addresses: The Oka-Terrace State Reservation: U.S.S.R., Moscow Region, Serpukhov District, Post Office Danka. U.S.S.R. Academy of Sciences Experiment Station, Institute of Agricultural Chemistry and of Soil Science: USSR, Moscow Region, Serpukhov District, Pushchino on the Oka.

THE CENTRAL CHERNOZEM BIOSPHERE RESERVE

The Central Chernozem Reserve is located within the central Russian highlands. The average altitude of the reserve is 250 m above sea level. The reserve area is 4 795 ha.

In consideration of the historically developed conditions, the reserve has a four-field hay-mowing regime. Each part of the steppe is mowed for three years and remains unmowed for one year. Constantly unmowed areas (having absolutely protected character) and areas for grazing have also been established in the reserve for comparative studies. In this way, the reserve includes all variations of steppe phytocenoses (mowed, unmowed, and grazed). In addition, there is a 1 km wide protection zone along the borders of the reserve. It functions as a buffer zone and reduces the influence of man's economic activities on the reserve. The total protected area is 8 663 ha. Economic activities within the protected areas are regulated.

Flora

The flora and vegetation of the Central Chernozem Reserve is typical for forest steppe in the European part of the U.S.S.R.

Additional Information

References: Works of the Berezina Reservation: The Berezina Reservation. No. 1 (1970), No. 2 (1972); the Reservation on the Berezina, Publishing House "Harvest", Minsk, U.S.S.R. 1974.

Staff: There are presently 270 members of the full-time staff.

Budget: The annual budget of the reserve is 500,000 rubles.

Address: U.S.S.R., 211188, Byelorussian Soviet Socialist Republic, Post Office Domzheritsa, Lepel' District, Vitebsk Region.

THE OKA-TERRACE BIOSPHERE RESERVE

The Oka-Terrace Reserve is located in a valley on the left shore of the Oka River, 12 km to the east of Serpukhov, and 100 km south of Moscow. The reserve and the station are located in the square 54 to 55° northern latitude and 37 to 38° eastern longitude. The elevation of the reserve is 180 to 200 m above sea level with a reserve area of 4 945 ha.

The entire territory of the reserve is strictly protected. There are no buffer or other zones. In the northwestern part of the reserve there is an isolated area of 200 ha where a nursery was built for breeding aurochs.

Since 1976, the U.S.S.R. Academy of Sciences Experiment Station of the Institute of Agricultural Chemistry and Soil Science has carried out biosphere observations in collaboration with the reserve There is a regular bus service with Pushchino on the Oka and Serpukhov.

Flora

The Oka-Terrace Reserve is located in the central part of the eastern European plain at the boundary of the broadleaf and mixed forest subzones. The reserve is covered by forests. The main forests are a rich variety of pine forest types. The vegetative cover of the reserve also includes: unique relict meadow-steppe phytocenoses with a large number of steppe and rare mountain species (e.g., *Aconicum authora, Conex obtusata, Dentaria tennifolia*) broadleaf forests of oak and linden; spruce forests and sphagnum swamps with elements of taiga flora (e.g., *Andromeda politolia, Oxycoccus quadripetalus,* and *Drosera rotundifolia*); and unusual steppe plants (e.g., *Stipa jeannis, Festuca sulcata, Phleum phleoides Tulipa biebersteiniana, Cerasus fruticosa,* and *Veratum nigrum*) and other species (about 50) which are separated from their basic distributional area by 200 to 400 km.

Fauna

Fifty-three species of mammals and more than 130 species of birds are registered at the reserve. Among the basic species are representatives of broadleaf forests (e.g., [illegible], *Apodemus flavicollis*, and *Discus viridis*); of the taiga zone (e.g., *Tetrao urogallus*, and *Tetrastis bonasia*); of open spaces (*Microtus arvalis*) and others (e.g., *Vulpes vulpes*, *Sorex araneus*, and *Alces alces*). River beaver, roe deer, and wild boar live on the reserve and in neighboring areas. Aurochs are bred under nursery conditions.

Additional Information

References: Works of the Oka-Terrace Reservation: Nos. 1-5 (1957, 1958, 1961, 1961, 1971); a pamphlet "The Oka-Terrace State Reservation," Moscow, 1974 (in Russian and English).

Staff: Full-time staff is presently 70.

Budget: The annual budget of the reserve is 140,000 rubles.

Addresses: The Oka-Terrace State Reservation: U.S.S.R., Moscow Region, Serpukhov District, Post Office Danka. U.S.S.R. Academy of Sciences Experiment Station, Institute of Agricultural Chemistry and of Soil Science: USSR, Moscow Region, Serpukhov District, Pushchino on the Oka.

THE CENTRAL CHERNOZEM BIOSPHERE RESERVE

The Central Chernozem Reserve is located within the central Russian highlands. The average altitude of the reserve is 250 m above sea level. The reserve area is 4 795 ha.

In consideration of the historically developed conditions, the reserve has a four-field hay-mowing regime. Each part of the steppe is mowed for three years and remains unmowed for one year. Constantly unmowed areas (having absolutely protected character) and areas for grazing have also been established in the reserve for comparative studies. In this way, the reserve includes all variations of steppe phytocenoses (mowed, unmowed, and grazed). In addition, there is a 1 km wide protection zone along the borders of the reserve. It functions as a buffer zone and reduces the influence of man's economic activities on the reserve. The total protected area is 8 663 ha. Economic activities within the protected areas are regulated.

Flora

The flora and vegetation of the Central Chernozem Reserve is typical for forest steppe in the European part of the U.S.S.R.

The reserve includes colorful broadleaf/grain meadow steppes, oak forests and associations with relict plants of the glacial period. Higher vascular plants total 863 species. These include 12 special species which are included in the Redbook of rare and endangered plants of the U.S.S.R.: *Adonis vernalis, Cotoneaster alaunicus. Crambe tataria, Fritillaria ruthenia, F. meleagris, Lilium martagon, Stipa pennata,* and others. Complex structures are a characteristic feature of the steppe associations of the reserve. The oak forests of the reserve are rare. Their extensive clearings are steppes. The most widespread oak forest types are: goutweed oak forest, mixed-herb oak forest, and bracken oak forest.

Fauna

The fauna of the reserve is typical of the Central forest steppe. There are 39 species of mammals, 150 species of birds, and several thousand species of insects. There is a high density of beasts of prey (birds and mammals) and of ungulates (elk, roe deer, and wild boar). The entomo-fauna of the reservation, in addition to widely spread European-Siberian groups, includes boreal, steppe, and Mediterranean species.

Research Possibilities

Long-term station-based studies of the forest steppe complex have been underway for many years. These concern the water and temperature regimes of the soil and dynamics of vegetation and animal populations on a seasonal basis and over many years. Detailed studies of the structural and functional organization of the dominant biocenoses of the forest steppe are carried out jointly by the Reserve and the U.S.S.R. Academy of Sciences Institute of Geography Experiment Station.

The Central Chernozem Reserve, since it is located in a region of intensive agriculture and developed industry, is able to successfully fulfill the role of a baseline area for the observation of changes in the natural environment.

Additional Information

References: Works of the Central Chernozem Reservation: Nos. I-II (1948-1971); Central Chernozem State Reservation named after Prof. V. V. Alekhin. Moscow, Publishing House "Forest Industry", 1968.

Staff: The permanent staff of the reserve totals 70.

Budget: The annual budget is about 100,000 rubles.

Address: U.S.S.R., 307028 Kursk, Post Office Zapovednoe, Central Chernozem Reservation.

SIKHOTE-ALIN' BIOSPHERE RESERVE

This reserve is in two parts: the main section is in the mountains of the central Sikhote-Alin' and a smaller section is along the Sea of Japan in the RSFSR Primorskie region. The reserve is located in the square 44°50' to 45°50' northern latitude and 135°45' to 136°45' eastern longitude. The elevations of the main watershed ridge of the Sikhote-Alin' on the reserve vary between 1 000 to 1 200 m above sea level. Some peaks reach 1 500 to 1 600 m. Elevations of the watershed frequently fall to 600 m. Low mountains are located along the Sea of Japan with elevations of 300 to 400 m. A small area is occupied by coastal lowlands. The reserve occupies 340 200 ha The larger section is about 330 000 ha and the section along the Sea of Japan is 10 000 ha. The reserve has a buffer zone along its borders which is 1 km wide and has protection status.

At present a protection regime is observed on the entire reserve. Biogeocenoses which have undergone little modification are found on the territory of the reserve; these biogeocenoses undergo successful restoration without human intervention. The reserve is surrounded by a protective 1-km buffer zone. There are considerable forest areas next to the reserve subjected to constant intensive economic use. Two highways, with a total length of 70 km, go through the reserve.

Flora

The reserve is located within the limits of the east Asian coniferous-broadleaf and the South Okhotsk dark coniferous forest area--forests dominate. The east and west macroslopes of the Sikhote-Alin' are heterogeneous in vegetative composition. The dominant formation on the sea side part of the reserve consists of broadleaf-cedar forests where *Pinus koraiensis* dominates. The mainland side has dark coniferous fir-spruce forests with *Abies nephrolepis* and *Picea ajanensis*. In the main part of the reserve are unique cedar-fir-spruce forests with understory *Rhododendron fauriei* relict groups with *Echinopanax elatium*, and broadleaf-coniferous forests with *Primula jezoensis* in the ground cover. Slope exposure, altitude, temperature inversions, and other factors strongly influence the vegetation resulting in a shifting of belts. Generally the zones are clearly expressed; however, natural and purportedly natural valley broadleaf-cedar forests have the greatest floral variety. They contain more than 30 tree species, shrubs, and lianas and more than 80 grass species. The vegetation of the reserve includes representatives of the Manchuria, Okhotsk, eastern Siberia, and Mongolian-Daur types. The flora is saturated with relict and endemic forms and shows a wide compositional variety. The list of flora of the reserve presently includes 940 species of higher plants including 46 tree species and 68 shrub species.

Fauna

The reserve is rich in such southern animal species as goral, tiger, and Himalaya bear. Simultaneously, we find musk deer, wolf, glutton, brown bear, and many other palearctic species. On the whole, the animal world of the reserve is rich and diverse. We find 60 species of mammals, more than 300 species of birds, 12 species of amphibians and reptiles, and more than 30 species of fish.

Research Possibilities

During its existence, the reserve has conducted inventories of the flora and fauna, studied the biology and ecology of certain species of plants and animals (with rare and valuable species assigned highest priority), and collected information about natural ecosystem processes. Recently, work on problems posed by protection, reproduction, and rational utilization of the natural resources of the region has been intensified. The center is located in the district center of the settlement Ternei of the Primorskii region, on the shore of the sea. Vladivostok (660 km) and Khabarovsk (700 km) are the closest major administrative centers.

Additional Information

References: Works of the Sikhote-Alin' Reservation, Nos. 1-6; Collection: Flora and Vegetation of the Seaside Areas of the South of the Far East. (Works of the U.S.S.R. Academy of Sciences and the Sikhote-Alin' Reservation, new series, vol. 24, 127; 1975).

Staff: There are 90 permanent members on the staff of the reserve.

Budget: The annual budget of the reserve amounts to 260,000 rubles.

Address: U.S.S.R., 692150, Primorskii Region, Settlement Ternei, Sikhote-Alin' Reservation.

THE SARY-CHELEK BIOSPHERE RESERVE

This reserve is located between the spurs of the Chatkal mountain range facing towards the southeast. It is located in the southwestern part of the Kirghiz Soviet Socialist Republic to the northeast of the city Namagan, at 42° northern latitude and 71° eastern longitude. The elevation of the territory fluctuates from 1 200 to 4 300 m above sea level. The area covers 23 868 ha.

At present the reserve is divided into two basic zones: a zone of absolute protection and a buffer zone with forest cultivation and forest-related activities.

lora

The flora of the reserve includes about 1,000 species of plants, ong them 32 species of trees, 80 species of shrubs, and 886 species f herbs. The forest-shrub vegetation of the reserve is typical r the entire southern Kirghiz forest-fruit area. Representatives f the north and of the south are combined: relict walnut and firs *bies semienovii*), spruce (*Picea areukiana*), and grapes. The evational zones are clearly expressed in the vegetation distri- tion. Walnut is the dominant in the nut-fruit forests. Among e sparse growth of trees are found groups of apple and pear trees th an underbrush of *Prunus spinosa, abelia,* and *exochordia* and *niperus taurica.* In the upper part of the belt the nut trees are placed by spruce and spruce-fir trees. The apple tree forests cupy smaller areas in comparison with the nut forests. Thickets f prangos strike one's attention among the apple tree forests. e subalpine belt goes from a height of 2 100 to 2 200 to 2 500 to 000 m. In its lower part *Juniperus taurica* and fir-spruce forests re present. The trees and bushes become rare with increasing ltitudes, gradually yielding to subalpine meadows with thick rbage.

auna

The reserve territory presently has 41 species of mammals, in- luding 5 acclimatized species; 157 species of birds, 118 of which uild nests; 5 species of reptiles; 2 species of amphibians; and species of fish. The animal world, in both species numbers and umbers of individuals, is most richly represented in the forest elt. Wild boar and a large number of roe deer are the most haracteristic large animals in this belt. In the fall the hite-clawed bear is present in the nut-fruit forests. The animal orld of the alpine and subalpine belts is distinct. In the eserve, there are mountain goats and mountain sheep as well as now leopard. Ermine and stone marten can be found everywhere.

uman Impact

Since 1960 there has been no economic activity in the protection one. Fire prevention and biotechnical measures are carried out n the buffer zone.

esearch Possibilities

At present the reserve staff inventories flora and fauna and studies the biology and ecology of some species of mammals (beasts f prey and ungulates) and of birds. Special attention is given o the structure of the vegetative cover and the special features f the main species of fruit and commercially valuable trees and hrubs. This area can serve in an international research program s a baseline area for comparative indices on pollution. The erritory is accessible for research.

Additional Information

References: A. I. Yanushevich and Yu. N. Chichikin: "The Sary-Chelek Reservation," in the collection "Reservations of the Soviet Union." Moscow. Publishing House "Mir", 1960; Works of the Reservation, Nos. 1-4.

Staff: There are 110 members on the permanent staff on the reserve.

Budget: The annual budget amounts to 90,000 rubles.

Address: U.S.S.R., 715705, Kirhiz SSR, Osh Area, Dzhangi-Dzhol' District, settlement Arkit, Sary-Chelek Reservation.

THE REPETEK BIOSPHERE RESERVE

The Repetek Reserve and the Sand-Desert Station are located in the Kara Kum desert, 70 km from the valley of the river Amu Darya, at 38° to 39° northern latitude and 63°00' eastern longitude. The elevation of the reserve is 180 to 220 m above sea level. The total area of the reserve is 34 600 ha. The Repetek Reserve is located in the central part of the eastern Kara Kum.

Zoning

The natural or nuclear zone can be identified in the territory of the Repetek Reserve and on areas close to it. The Reserve totals 15 000 ha. There is a desert portion which is completely intact. It includes the basic land forms of mobile and stabilized sands, basic vegetation formations of the Kara Kum, and the most characteristic representatives of the animal world. There are also experimental or buffer zones totalling 19 600 ha. Various experiments can be carried out in this area such as shrub cutting, cattle grazing, and stabilization of mobile sands.

Flora

The flora of the reserve is represented by 125 species of plants which belong to 24 families. Most characteristic are species of the families Chenopodiaceae (*Halolyxon persicum, H. ammodendron*), Doligomaceae (species of the genus *Calligonum*), Leguminosae, Cyperaceae, Gramineae, and others. Mosses are represented by one species (*Tortula desertorum*). The flora of higher fungi includes eight species, mainly species of the family Agaricaceae. The flora of the reserve is typically highly specialized along the line of *xerophily* and *psammophily*, and there are a large number of endemic species (37 percent).

The vegetation cover is represented by associations of four formations of desert vegetation: *Calligonum arboresceus, C. caput-medusae, Haloxylon persicum,* and *H. ammodendron.* Formations of *Calligonum* sp. can be found on mobile and weakly stabilized sands

and occupy 34 percent of reserve. The White Haloxylon formation includes various associations. The most characteristic of these are *Haloxylon persicum-Austida pennata* which are developed on hilly sands slightly covered by grass and *H. persicum-Carex physodes* and *H. persicum-Carex physodes-Tortula desertorum*, which are characteristic for stabilized hilly sands. Associations of this formation occupy 44 percent of the reserve. Associations of the Black Haloxylon formation occupy a small area (5 percent) on valley-like lowlands. They are characterized by the greatest productivity of any of the sand desert associations.

Fauna

In the Repetek Reserve there are 19 species of reptiles and 21 species of mammals. Twenty-five species of birds build nests, and 12 are resident. In spring and fall 150 species of birds can be seen in the reserve. About 1,000 species of invertebrates live in the reservation. The biggest lizard in the Soviet Union (*Varanus grisemus*) is found regularly as well as one of the biggest carabus (*Anthia mannerheimi*). The only poisonous snake (*Echis carinatus*) is common. On the whole, the reserve fauna is characterized by psammophily and by a significant number of endemics. Among the endemic vertebrates of the sand deserts of Tutan, *Eryx miliaris, Diplomesodon pulchellum, Paradipus stenodactylus, Jaculus lichtensteini*, the thin-fingered gopher, and the Haloxylon jay are found on the reserve. About 70 percent of the invertebrates are endemics, a large part of which are found mainly in the sand deserts of the southern subzone. Seven species of rare and threatened animals, which can be found in the USSR Redbook, live in the reserve: *Varanus grisemus, Gasella subgutturosa, Felus caracal, Vormela peregasua, Arcaetus callicus, Agailla chysaetus* and the desert sparrow (*Passer simplex*).

Human Impact

Human impact is absent in the natural zone. A moderate and, in places, significant grazing by sheep and cattle can be observed everywhere in the experimental zone. Natural methods for the restoration of natural conditions currently at different stages of anthropogenic change should be studied in this area in addition to methods of technical melioration and phytomelioration.

Research Possibilities

Long-term scientific studies of the Repetek Sand-Desert Station and Reserve include: the seasonal and long-term dynamics of some components of the sand-desert ecosystems; soil moisture regime; phenology, productivity and successive changes of the vegetation cover; composition and distribution of animals; and development of scientific foundations for a vegetation-oriented assimilation of desert territories, such as silviculture in the sand desert and the rational use of plant resources. At present, the main attention

is directed toward complex studies of the most typical ecosystems of the sand desert, of sand-hill sands with rare vegetation, of silt White Haloxylon communities on hilly sands, and of Black Haloxylon communities along valley-like lowlands. Most ecosystem studies were carried out under protected conditions. In international research, the Repetek Reserve occupies an important place, being a primary research site in the International Biological Program (IBP). The reserve and the Sand-Desert Station have railway and automobile connections with the large cities of Central Asia and are completely open to scientists. The regional center, the city Chardzhou, is 70 km from the reservation.

Additional Information

References: Miroshnik, V. P.: The Repetek Sand-Desert Reservation. In the book: "USSR Reservations", vol. 2, Moscow, 1951; Works of the Repetek Sand-Desert Station, vol. 3, Ashkhabad, 1955, USSR Academy of Sciences Publishing House; Works of the Repetek Sand-Desert Station, Ashkhabad, 1963, Turkmen SSR Academy of Sciences Publishing House. Studies and Development of the Eastern Kara Kum, Ashkhabad, Publishing House "Ylym", 1972; Biocenoses of the eastern Kara Kum, Ashkabad, Publishing House "Ylym", 1975; Rodin, L. E. (ed.): The Productivity of Desert Associations. In the collection: "Biosphere Resources", No. 1, Leningrad, USSR Academy of Sciences Publishing House, 1975.

Staff: There are 25 permanent members of the staff of the Repetek Sand-Desert Station and of the Turkmen SSR Academy of Sciences Reserve.

Budget: The total budget of the station and of the reserve amounts to 60,000 rubles.

Address: USSR, 746060, Turkmen SSR, Chardzhou Region, Station Repetek of the Central Asian Railroad, Repetek Reservation.

* * * * * * *

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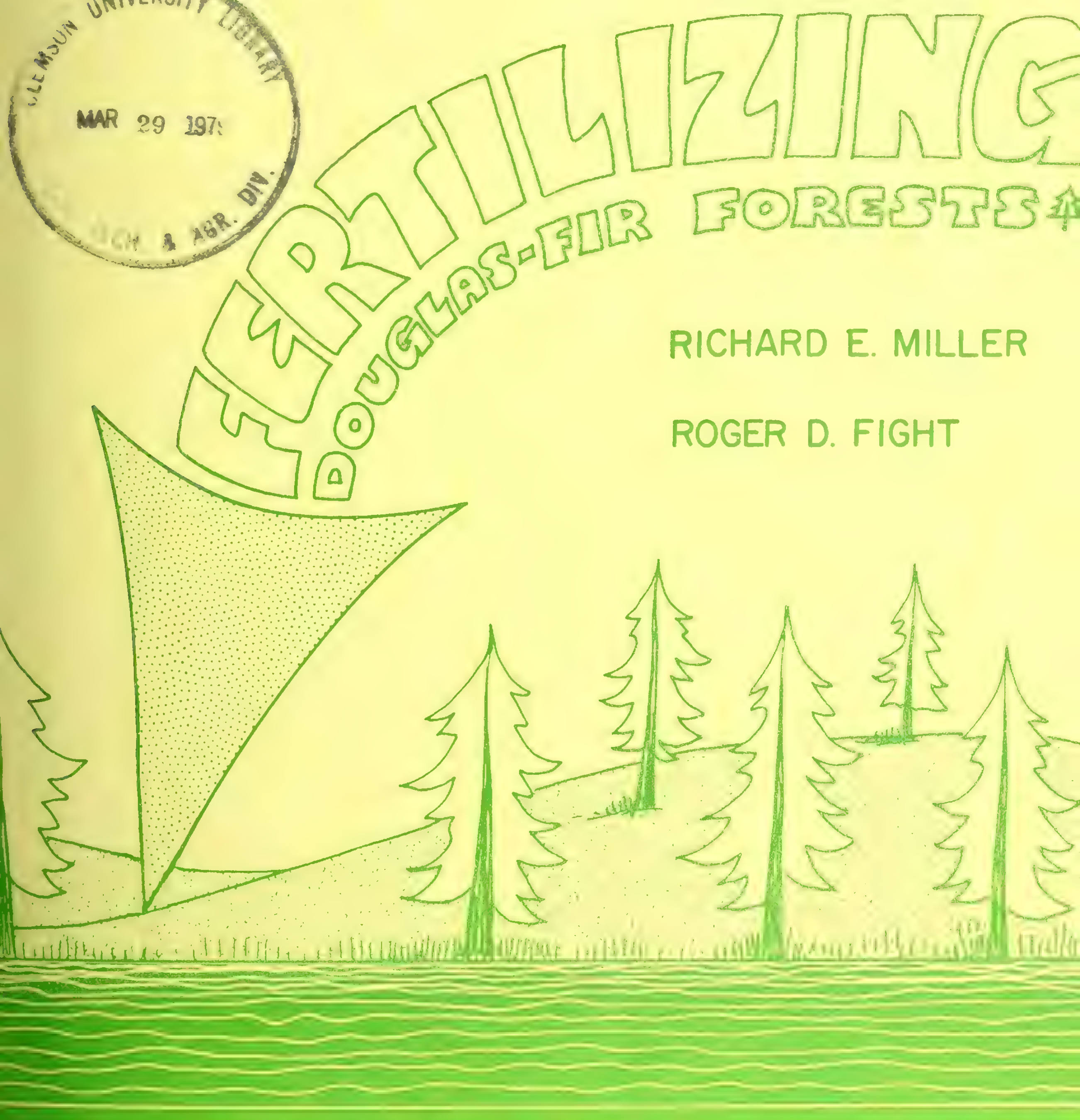

RICHARD E. MILLER

ROGER D. FIGHT

IFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
S. DEPARTMENT OF AGRICULTURE FOREST SERVICE

Preface

Fertilizing Douglas-fir Forests [1/]

This report is in two parts. In Part I, we will discuss some of the biological bases of forest fertilization and describe the current practice of operational fertilization. We will then discuss both the reliability of fertilization for increasing tree growth and its environmental impacts. In Part II, we will show how to evaluate the economics of forest fertilization.

After reading and referring to this report, you should be able to:

1. Describe the current practice of fertilizing Douglas-fir forests, i.e., fertilizer prescription and stand selection.

2. Describe the effect of N fertilizer on Douglas-fir growth.

3. Cite evidence about some environmental impacts of N fertilization and use this information to prepare Environmental Assessment Reports.

4. Enumerate and discuss factors that affect the costs and revenues from investments in forest fertilization.

5. Use the accompanying worksheet to prepare a break-even analysis for your fertilization projects.

[1/] This General Technical Report supplements a slide-tape presentation titled, Fertilizing Douglas-fir Forests. This slide tape (772.1-.2 S-T) is available for rent or purchase from The Forestry Media Center, School of Forestry, Oregon State University, Corvallis, Oregon 97331.

PART I. Biological Bases and Effects of Nitrogen Fertilization

Yields From Douglas-fir Forests

UNMANAGED FORESTS

Douglas-fir is the predominant tree species in nearly one-half of the commercial forests in western Washington and Oregon. Yield from natural, unmanaged stands varies greatly and largely depends on the number of trees occupying a site and the inherent productivity or quality of the site. For example, harvesting of all live trees from a normal site quality V stand at 60 years would provide about 3,500 cubic feet per acre (McArdle et al. 1961) or enough wood to build one typical three-bedroom house (fig. 1). In contrast, harvesting all live trees from a normal 60-year-old, site I stand would yield about 12,500 cubic feet per acre or enough wood to build nearly four typical houses!

The two solid lines in figure 1 represent trends in gross yield. Gross yield is the volume of live trees plus mortality, i.e., the cumulative volume of trees normally lost through competition, insects, and disease. This mortality volume averages about 20 percent of the total or gross growth of unmanaged, well-stocked stands of Douglas-fir. Reducing or salvaging this mortality volume can increase usable yields from our forests.

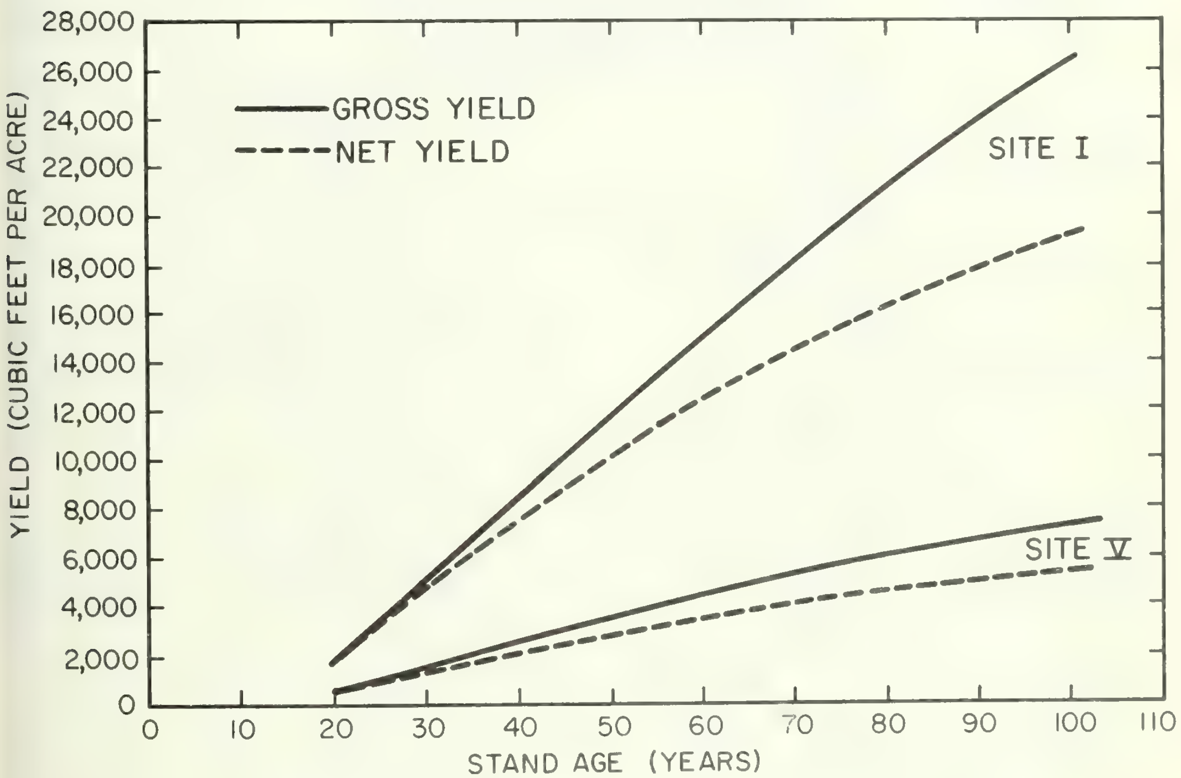

Figure 1.--Normal yields of Douglas-fir (derived from McArdle et al. 1961 and Staebler 1955).

MANAGED FORESTS

Most volume normally lost in unmanaged forests can be recovered in managed forests. By precommercially thinning young stands, foresters eliminate excess trees that will not reach merchantable size and thereby concentrate growth onto future crop trees. By commercially thinning older stands, dead trees of merchantable size are salvaged as part of the thinning operation.

In addition to controlling numbers and sizes of trees which share the site, foresters can increase site productivity by improving environmental conditions. Some environmental factors can be manipulated with relative ease, but others like temperature and precipitation are difficult to change. Moreover, correcting the initial growth-limiting factor will increase growth until some other factor becomes limiting. This principle is illustrated by the barrel analogy (fig. 2).

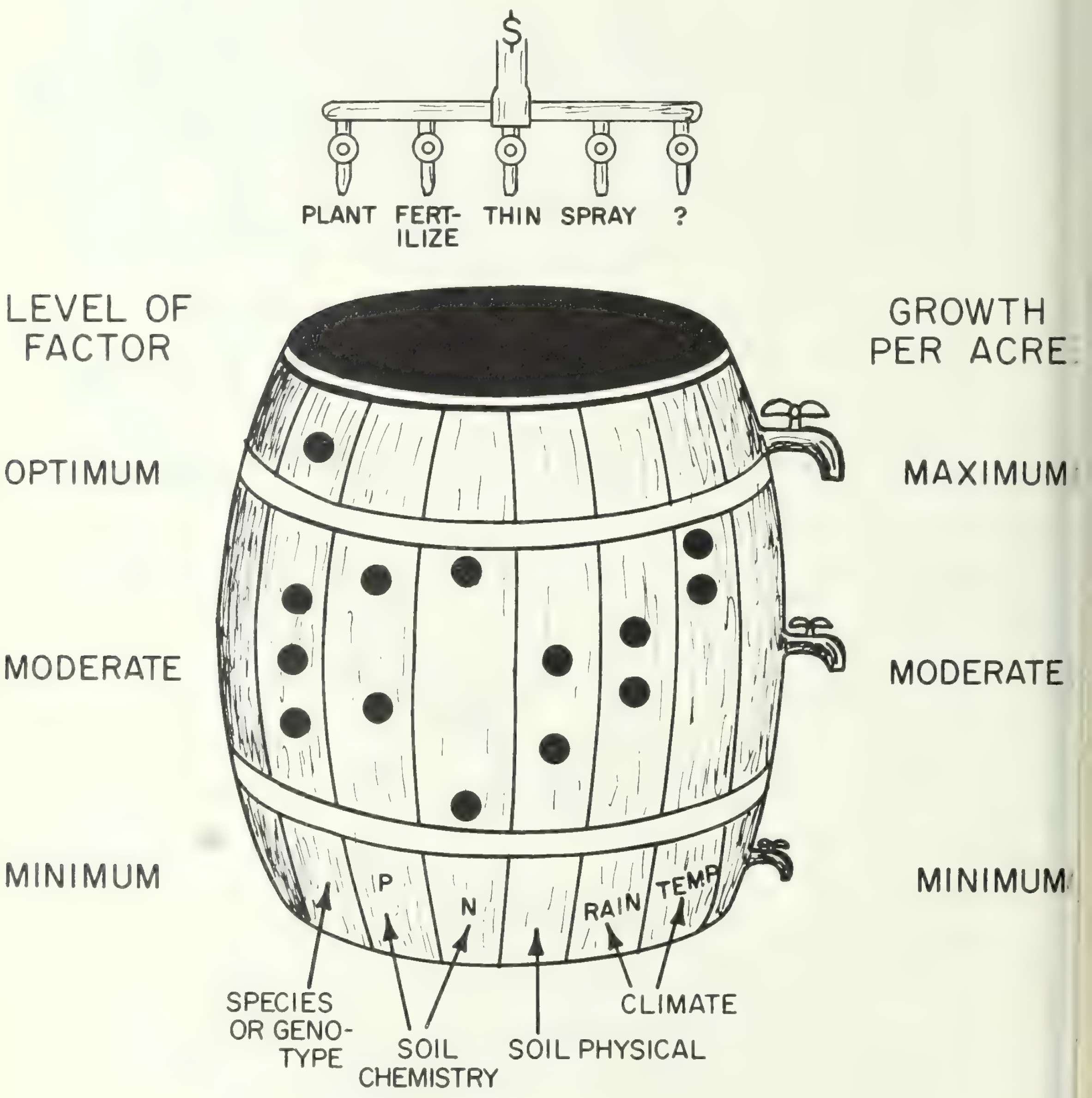

Figure 2.--Improving site quality.

Consider this barrel a forest site we want to improve. Each stave of the barrel represents a productivity factor. The level of production obtainable at this site is limited by the factor with the lowest opening in the barrel. In this example, the amount of available nitrogen is the first growth-limiting factor. If we remedy this by applying nitrogen fertilizer, we plug this weakness and increase production to the next factor in short supply. This next factor may be a physical property of the soil like compaction or stoniness. We can readily improve compaction in the surface soil by mechanical means, but correcting stoniness is usually too costly. Therefore, on this theoretical site--as in a practical field situation--we would add nitrogen until production was limited by some factor beyond our control.

Fertilization to Increase Yield

THE CURRENT PRACTICE

Forest fertilization is developing into a practical means for increasing yields of Douglas-fir forests of western Washington and Oregon. This commercial practice was preceded by numerous field trials where fertilizer was spread uniformly over the soil and trees were carefully measured for growth in diameter and height. These trials have provided direct evidence that nitrogen fertilizers can increase growth of established stands; direct evidence led to large-scale applications.

The first operational fertilization was in 1965 when 1,500 acres of Douglas-fir on Crown Zellerbach's holdings near Molalla, Oregon were treated with urea prills, small, white spheres of nitrogen fertilizer. For the 10-year period of 1965 through 1974, nitrogen fertilizer was applied to at least 825,000 acres in western Washington and Oregon.[2/] About 90 percent of this acreage was industry-owned forests. Helicopters were used almost exclusively to fertilize these forests. Generally, the prescribed treatment was 150 or 200 pounds of elemental nitrogen per acre, applied as urea prill or larger forestry-grade granules.

[2/] Personal communication with Robert T. Bergland, former Fertilization Forester, Washington State Department of Natural Resources, Olympia, Washington, on October 22, 1975.

WHAT WE KNOW

Although fertilization has joined traditional management tools like planting and thinning to increase wood production, researchers and land managers are continuing to improve gains from fertilization. We currently have general answers to questions concerning which nutrient elements, dosages, and fertilizers should be used, and when and how they should be applied. Refining these general answers will increase the gains from current practices.

Which nutrients?--Current applications of nitrogen are based on past observations that nitrogen fertilizers frequently increase growth of Douglas-fir at a wide range of locations. Other elements such as phosphorous, potassium, and sulphur have also been tested in combination with nitrogen; but these elements seldom improve the gain achieved from applying nitrogen alone in the Pacific Northwest (Gessel et al. 1965, Crossin et al. 1966, Steinbrenner 1968, Heilman 1971, Miller and Reukema 1974).

Douglas-fir, like other plants, requires relatively large quantities of nitrogen compared to most other elements. For example, productive stands annually require 40 to 100 pounds of nitrogen per acre. Most of this annual requirement is met by the roots which extract inorganic nitrogen from the soil and forest floor; however, some of this requirement is provided by internally recycling N extracted in previous years. Although soils of commercial Douglas-fir forests contain 2,000 to more than 20,000 pounds of nitrogen per acre (Gessel et al. 1972), most of this nitrogen is trapped in living organic matter or organic residues. Each year, only a small

fraction is mineralized into inorganic nitrogen and made available to trees, other plants, and micro-organisms, all of which compete for this limited nutrient. Rates of N turnover in many stands are frequently inadequate to meet tree requirements, as shown by the response that usually follows fertilization with 150 or more pounds of nitrogen per acre.

How much?--The biologically and economically optimum fertilizer dosage for established stands of Douglas-fir probably lies between 150 and 300 pounds of nitrogen per acre. Lesser amounts may fail to provide measurable effects. Larger amounts may provide slightly more volume and longer duration of response (fig. 3), but in some locations can lead to increased mortality (Lee 1974) or snow or winter breakage brought on by sudden stimulation of foliar growth (Miller and Pienaar 1973).

Which source of N?--Most nitrogen fertilizer currently applied to Douglas-fir forests is urea. Urea is used primarily because of its relatively low initial cost per pound of nitrogen and because its higher concentration of nitrogen (46 percent) provides a greater net payload than other nitrogen fertilizers like ammonium nitrate (34 percent) (table 1).

Table 1--Pounds of fertilizer to apply (per acre basis)

Desired nitrogen dosage	Fertilizer source	
	Urea (46-0-0)	Ammonium nitrate (34-0-0)
150	[1] 326	441
200	435	588

[1] Calculation: $\frac{150}{0.46} = 326$

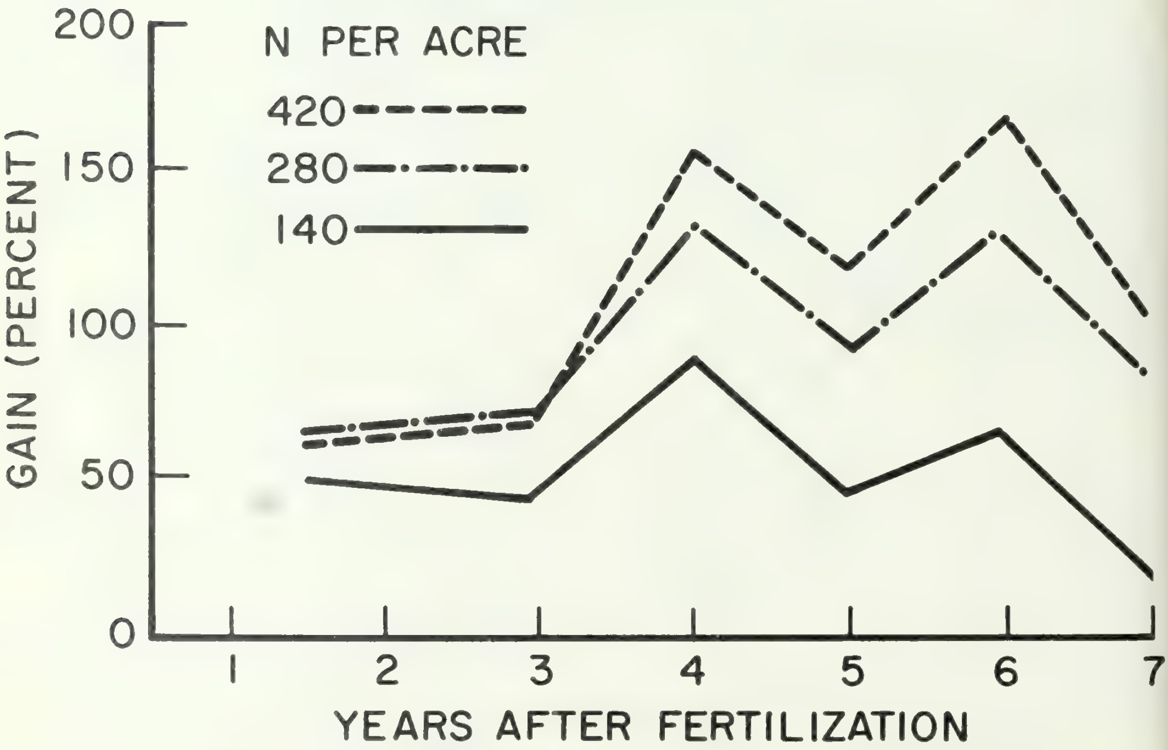

Figure 3.--Gain in gross volume growth, 35-year-old Douglas-fir (Miller and Pienaar 1973).

Application of urea during periods of dry, warm weather should be avoided because such climatic conditions could lead to gaseous losses of nitrogen and reductions in the amount available for growth (Watkins et al. 1972). The performance of urea and other sources of N is being compared under forest conditions; currently, however, we cannot specify circumstances where specific fertilizers will provide the greatest response per pound of nitrogen applied.

Stand age?--Biologic and economic considerations determine when to fertilize Douglas-fir stands. Fertilization at time of tree planting has seldom been beneficial (Austin and Strand 1960). Adding fertilizer pellets to the planting hole has not proved cost-effective, and broadcast applications of nitrogen to seedlings usually increase competition from other vegetation and reduce seedling survival.

Because nutrient demands are usually highest when annual rates of wood production and crown expansion are highest, it is biologically desirable to fertilize initially when the Douglas-fir stand is between 15 and 20 years old. Although this timing is likely to provide large gains in wood volume, it may not provide greater economic gains than fertilizing at a later period when the trees have reached a merchantable size. As we explain in Part II, the period of time between the fertilizer investment and the harvest of volume gained from this investment strongly influences economic benefits of fertilization.

IS FERTILIZATION A SUITABLE TOOL?

Land managers can use several criteria to judge the merits of fertilization. Specifically, they want to know how reliable forest fertilization is, how environmentally safe it is in the forested watershed, and how much economic return it will provide. In the remainder of Part I, we'll see how well fertilization meets the criteria of reliability and environmental impact. In Part II, we'll examine the economics of forest fertilization.

How Reliable is Forest Fertilization?

Foresters want a tool that will enhance growth over a wide range of forest conditions, and they want a high probability of getting improved growth after using this tool.

PROBABILITY OF RESPONSE

Some indication of the reliability of nitrogen fertilization is provided by results from the cooperative regional fertilization trials conducted at numerous locations in western Washington and Oregon by University of Washington researchers (Atkinson 1974). Of 87 unthinned stands of Douglas-fir tested, 72 percent responded with increased volume growth of at least 10 percent within 2 years of being fertilized with 200 pounds of nitrogen per acre applied as urea (Regional Forest Nutrition Research Project 1975b). Moreover, the percentage of stands that showed at least a 10-percent response to nitrogen was somewhat greater in lower than higher site qualities:

	Stands	
Site	Total	Responding
	Number	Percent
I	11	64
II	38	66
III	25	84
IV	10	80
V	3	67
All	87	72

This broadly based sample indicates a 72-percent chance of obtaining at least a 10-percent growth improvement if nitrogen is applied to well-stocked stands of Douglas-fir. These odds can be improved if land managers can identify the most and least profitable acres for fertilization. Then, fertilizer expenditures can be programed selectively to increase reliability and profits. Several means to increase reliability will be discussed after describing some general effects of nitrogen fertilization on Douglas-fir.

EFFECTS OF NITROGEN FERTILIZER ON DOUGLAS-FIR GROWTH

Fertilized Douglas-firs usually increase growth in diameter and volume during the first growing season after treatment. Foliage of trees with a severe nitrogen deficiency darkens, lengthens, and remains on the tree for 1 or more additional years. These changes in foliage and greater branch growth indicate a more rapid build-up of tree crown and a greater potential for future growth.

Response in volume growth generally peaks between the 3d and 5th year after fertilization. Although duration of response varies with location, stand, and nitrogen dosage, current data suggest that response gradually approaches zero within 10 to 15 years after treatment.

Field trials during the past 25 years have demonstrated that addition of nitrogen usually increases growth of Douglas-fir over the full range of site qualities, sites I through V. Initial results from the previously mentioned cooperative trials in western Washington and Oregon show that application of 200 pounds of nitrogen per acre to low quality sites can provide a greater cubic foot gain than the same application on higher quality sites (Turnbull and Peterson 1976). During a 4-year observation period, average yearly gains from fertilized Douglas-fir stands ranged from 27 cubic feet on site I, through 91 cubic feet on site IV (table 2). Thus far, an average of 108 to 364 cubic feet of extra wood was produced by treatment; and these gains will probably double during the future growth of most of these stands.

The finding that low quality sites provided a greater cubic-foot gain from 200 pounds of nitrogen per acre than higher quality sites to the same dosage fits the barrel analogy discussed earlier. The most limiting growth factor on these lower quality sites was evidently insufficient amounts of available nitrogen. Fertilizing with nitrogen temporarily removed this limitation and, therefore, increased stand growth. Conversely, less response to fertilization occurred on the naturally more productive sites, probably because amounts of available nitrogen were not limiting growth as severely.

Table 2--Average gain from fertilizing Douglas-fir on sites I through IV[1/]

Site	Gain	
	Yearly	4-year
	Cubic feet	Cubic feet
I	27	108
II	48	192
III	70	280
IV	91	364

[1/] Fertilized with 200 pounds of nitrogen per acre as urea. Source: Adapted from Turnbull and Peterson (1976).

IMPROVING RELIABILITY

As suggested by results from the cooperative trials and earlier trials, site index of Douglas-fir stands in western Washington and Oregon is a basis for predicting response to nitrogen fertilizer. Response is greater and more likely on site IV land than on progressively higher site qualities. On site V and lower quality lands, however, the likelihood of response is less predictable for two reasons. First, from an empirical standpoint, fewer trials exist on such low sites to establish a reliable prediction. Second, from an intuitive standpoint and based on the barrel analogy, there is a greater likelihood that several factors besides available nitrogen will be at marginal levels and therefore will limit growth.

A second option is also available for predicting likelihood of fertilizer response. Chemical analysis of soil or foliage from proposed treatment areas has been used successfully in some agricultural crops and forest types to predict need for fertilizer. If close relationships exist between growth and the content of nitrogen in foliage or soil, then one can

reasonably predict that increasing the content of nitrogen by fertilization will enhance growth. Although such diagnostic techniques are being developed by several scientists for use in Douglas-fir (Lavender and Carmichael 1966, Shumway and Atkinson 1977),[3] they are not yet sufficiently developed for practical use.

Finally, the surest way to select responsive areas for operational fertilization is to match stand and soil characteristics of successful, experimental field trials (table 3).

Table 3--Stand response to nitrogen, an example of local experience to guide operational fertilization

Trial		Stand age	Soil number	Increased growth during period	
Number	Response period				
	Years	Years		Cubic feet	Percent
1	7	35	37	650	70
2	4	35	14	344	28
3	4	50	14	304	28
4	4	45	13	236	18

Having assembled experience data, a land manager can increase his certainty of achieving similar gains by fertilizing similar stands and soils. The closer the match, the more likely it is that similar gains will be obtained.

How Environmentally Safe?

The evaluation of probable effects of fertilization on the environment should precede the decision to fertilize. As stated by Tamm (1973, p. 306), "There is no simple answer to the question whether a forest fertilization improves or decreases the environmental quality of a site. Pros and cons have to be evaluated and weighed at each site."

Beneficial effects of fertilizing Douglas-fir forests include temporary improvements in vegetative color and growth of trees and associated vegetation and faster rates of nutrient cycling between the soil and the Douglas-fir stand (Miller et al. 1976). Negative environmental impacts are also probable. For example, temporary increases in road and air traffic and in audio and visual impacts are inherent to operational fertilization. The predominant concern, however, is excessive nitrogen in surface and ground waters. Specifically, increases in total nitrogen concentration can increase eutrophication, a natural but frequently nuisance growth of phytoplankton, algae, and aquatic weeds. Moreover, concentrations of nitrate-N exceeding 10 parts per million indicate the water is unfit for human consumption (NAS-NAE 1973).

RESULTS FROM STREAM MONITORING

Shortly after operational fertilization began in the Pacific Northwest, stream waters flowing from several forested watersheds in western Washington and Oregon were sampled before and after applications of 150 or 200

[3] Ian George Morison. Foliar nitrogen range and variability in a second-growth Douglas-fir forest and its relationship to certain stand and tree characteristics. Doctorate Dissertation. University of Washington, Seattle. 268 p. 1970.

pounds of nitrogen per acre as urea fertilizer. Initial results from this monitoring were summarized in a 1972 report of the Environmental Protection Agency (Groman 1972, p. 3):

> "A continual process of collecting and evaluating forest fertilization-water quality studies is required to supplement and refine current knowledge. The few studies conducted to date indicate no substantial or long-term detrimental effects on the environment associated with the practice...."

Water quality continued to be checked and results from 22 fertilized watersheds in Douglas-fir forests were reported by Moore (1974). He concluded that the maximum concentration of urea-, ammonia-, nitrite-, and nitrate-nitrogen in streams that were repeatedly sampled after forest fertilization easily met published standards for public water supplies.

The effects of increased nitrogen on stream habitat and esthetics are less definite. Thut and Hayden (1971) concluded that these increases in various forms of N found in streamwater after fertilization were well below toxic levels for aquatic life; they predicted that forest fertilization could increase aquatic productivity in nutrient-poor streams. Since most streams in forest watersheds of the Douglas-fir region are nutrient poor, this increase in nitrogen concentration and aquatic production could be considered environmentally desirable. Yet, fertilization could contribute to an undesirable condition outside the watershed, because increases in nitrogen concentration could increase eutrophication after mountain streams enter warmer, slower-moving streams or lakes at lower elevations. Clearly, the extent of fertilization in a watershed and the stream characteristics and land use downstream are key factors controlling the ultimate effect of forest fertilization on the aquatic environment.

Direct measurements of nitrogen in streams suggest that forest fertilization is compatible with accept[illegible] standards of water quality (NAS-NAE 1973). When reasonable precautions were taken to minimize direct application of fertilizer to major stream increases in nitrogen content of the water were primarily from fertilizer that was inadvertently dropped into small streams. Moore (1974 and 1975 provided typical results from three studies in stand conditions ranging from old growth to a young plantatio[illegible] (table 4). Helicopters applied 200 pounds of nitrogen as urea. Repeate[illegible] stream sampling during 29 and 52 wee[illegible] after fertilization showed the equiv[illegible]lent of less than one-half of 1 percent of the applied nitrogen was lost to streams.

Table 4--Loss of fertilizer nitrogen in streams after application of 200 pounds of nitrogen per acre as urea[1]

Area	Conditions	N-lost after designated period		
		Period	Per acre	Of application
		Weeks	Pounds	Percent
Coyote Creek	Old growth	52	0.34	0.17
Quilcene No. 1	Open and pole-sized plantation	29	.49	.25
Quilcene No. 2	40-year plantation	29	.67	.34

[1] Source: Moore 1974, 1975.

Nitrogen losses from fertilizer landing on the soil or forest floor are of less concern. Leaching losses through soil to streams or ground water occur primarily when nitrogen is in the nitrate-ion form; therefore, leaching may occur where ammonium or urea fertilizers are converted to nitrate by soil bacteria or if nitrate-containing fertilizers are applied. Although a laboratory study showed that many forest soils of the Pacific Northwest convert fertilizer nitrogen and organic nitrogen to nitrate ions (Heilman 1974), field investigations have detected only small quantities of nitrate in stream water after fertilization with urea (McCall 1970, Burroughs and Froehlich 1972, Moore 1974 and 1975). Correspondingly low nitrate concentrations were measured at the one location where ammonium nitrate fertilizer was applied (Moore 1974). Presumably, applied or biologically converted nitrate is readily taken up by soil organisms and vegetation.

AVOIDING A POTENTIAL PROBLEM

Although additional information is needed about the effects of repeated fertilization to the same area and about using fertilizer solutions as foliar sprays (Norris and Moore 1976, Miller and Young 1976), available information suggests that little environmental damage is likely if nitrogen fertilizer is carefully broadcast at current dosages and intervals on forested land. When undertaking current operational practices, however, desirable precautions include: (1) maintaining untreated buffer areas along major streams; this buffer should be recognizable by the pilot and sufficiently wide to reduce accidental drift of small fertilizer particles, (2) avoiding applications when spring snow melt or heavy storms greatly expand small tributary streams, and (3) suspending operations whenever wind or reduced visibility could lead to significant losses of fertilizer from the target area (Norris and Moore 1971).

ENERGY TRADE-OFFS

When fertilizing forests with nitrogen, we expend nonrenewable energy (fossil fuels, especially petroleum and natural gas) to increase photosynthetic efficiency and thus wood production. For example, a conventional fertilization requires the equivalent of about 50 gallons of oil to produce, transport, and spread 200 pounds N per acre as urea by helicopter. Conversely, we can burn the additional wood gained from fertilization to produce energy or substitute this wood for metal or plastic products derived from nonrenewable resources. Several authors discuss these energy trade-offs and the means and economics of obtaining them (Grantham and Ellis 1974, Grantham et al. 1974, Evans 1974, Boyd et al. 1976).

Reifsnyder and Lull (1965) and Smith and Johnson (1977) maintained that growing wood, especially in conifer forests, is one of the most efficient ways to use energy to capture more energy. Assuming a return of 2 cubic feet of wood per pound of N applied as urea fertilizer, Smith and Johnson (1977) estimated a gross return of about 12 units of energy for each unit invested in fertilization of Douglas-fir forests. This gross return is converted to net return by subtracting the energy necessary to harvest (Dykstra 1976) and supply the final product (National Academy of Sciences 1976).

For example, assuming (1) 200 pounds of N/acre produces an additional 400 cubic feet/acre of Douglas-fir roundwood and (2) each 100 cubic feet of green roundwood is equivalent to 3.3 barrels or 139 gallons of fuel oil (Hartman et al., n.d.), then the gross energy return from fertilization is 556 gallons of oil. Further, assuming 5.16 gallons of oil to harvest 1 cord of roundwood (American Pulpwood Association 1975) at 85 cubic feet of solid roundwood per cord, then harvesting this extra 400 cubic feet would require 24 gallons of oil and thus reduce the net energy return to 532 gallons of oil-equivalent for expenditures of 50 gallons to produce, transport, and spread 200

pounds of N per acre by helicopter. Therefore, the net ratio of energy gain in this example is 10.6.

Summary

The four major points of Part I follow:

1. Fertilization with nitrogen is a reliable means for increasing wood production in most Douglas-fir forests.

2. Current operational fertilization is based on past research findings. From 1965 through 1974, at least 825,000 acres of established stands of Douglas-fir in western Washington and Oregon were fertilized. The usual treatment consisted of 150 to 200 pounds of elemental nitrogen per acre applied as urea by helicopter during late fall through early spring.

3. Experimental trials indicate that land managers can reasonably expect from 200 to 800 additional cubic feet of stem wood per acre from fertilizing commercial forests. Results from cooperative trials show that gains in cubic volume from fertilizing Douglas-fir stands are inversely related to site quality. Thus, application of 200 pounds of N per acre to site IV and III stands can provide a greater cubic-foot gain than the same application on higher quality sites. Continuing efforts by researchers and land managers can improve volume and financial gains from forest fertilization.

4. Environmental damage is unlikely if fertilizer is carefully broadcast to minimize direct application into major streams.

PART II. How Economic?

Forest managers want a financial gain or profit from their investments in fertilization. This goal is reached when revenue gained from fertilizing exceeds the total costs of fertilizing. In this section, we shall first show how various factors influence economic returns. We will then present a break-even analysis to show how many cubic feet of extra growth are required and what stumpage prices are necessary to pay for assumed costs of fertilization. Finally, we'll discuss other financial considerations affecting fertilization decisions.

Treatment Costs

Costs of fertilizing clearly affect the profit from this silvicultural practice. The total cost has two components--the initial cost of fertilizing and the interest charges for carrying this investment.

INITIAL COSTS

The initial costs of fertilizing include the contract costs (supplying the fertilizer, transporting it into the forest, and applying it to specified areas by helicopter), and the costs of administering the contract, providing access roads and heliports, and in some instances, assessing water quality and tree response. Since the cost of fertilizer is usually 60-70 percent of the total treatment costs, the price of fertilizer strongly influences the initial cost of treatment.

Past costs of fertilization varied widely from year-to-year and from job-to-job. In 1970, the total cost of applying 200 pounds of nitrogen per acre averaged about $23. By 1974, when worldwide fertilizer and petroleum shortages developed, average costs more than doubled to about $57 per acre. On the income side of the financial ledger, however, stumpage prices increased by an even greater amount during the same period, so fertilization appeared to be a more attractive investment in 1974 than in 1970 (fig. 4).

One can minimize costs of a fertilization contract in at least two ways. As with most goods and services, the seasonal price for both fertilizer and application reflect supply and demand. Due to seasonal demands in agriculture, fertilizer prices are usually 3 to 5 percent lower in fall and winter. Application costs, however,

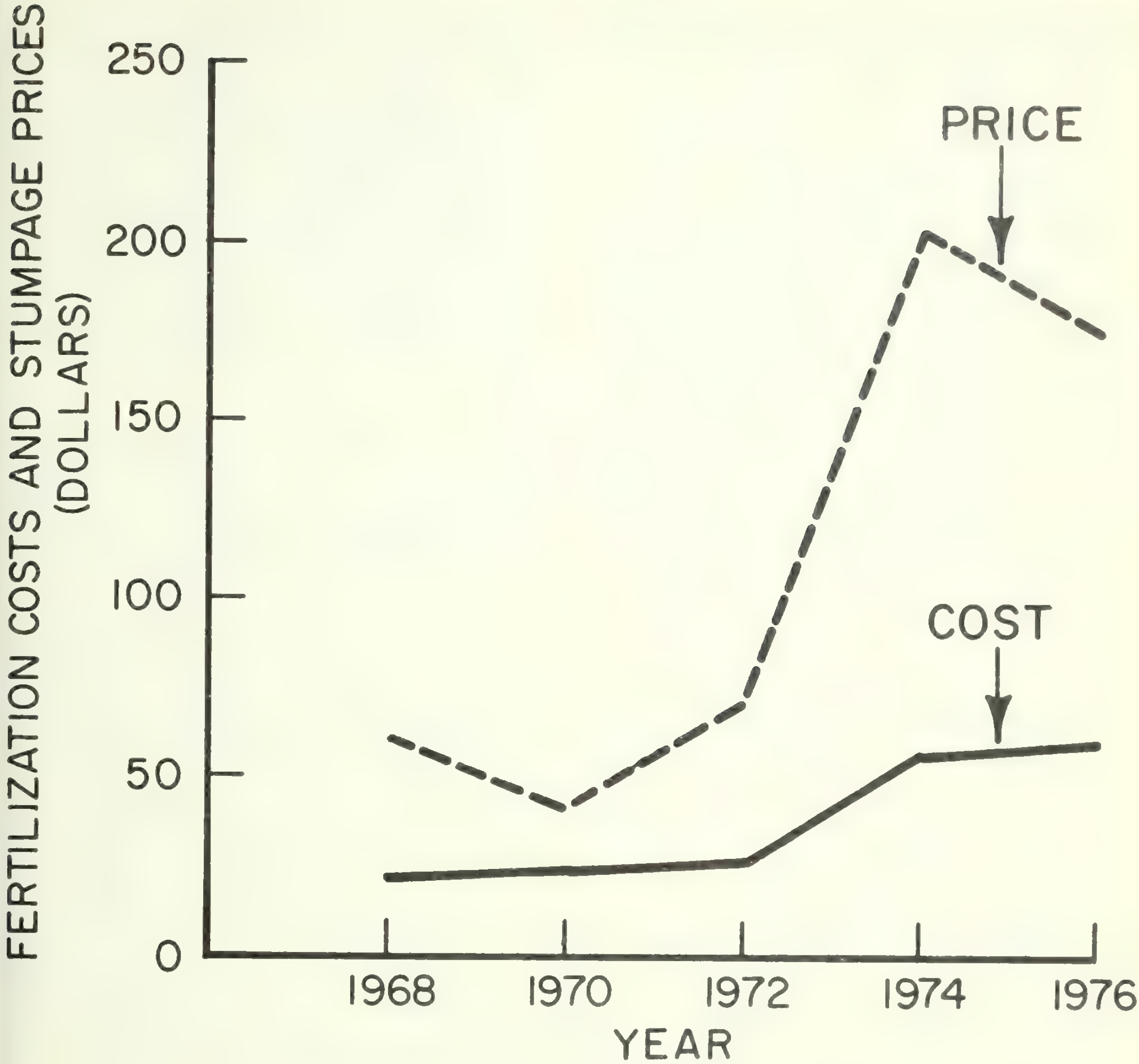

Figure 4.--Average fertilization costs and stumpage prices.

are generally much lower in spring, because many helicopters are contracted in fall for forest fire suppression. The net result is that fertilization contracts usually cost slightly less in spring.

A second way to reduce costs is to include as many acres as possible in the contract. Costs of fertilization per acre generally decline as the size of the contract increases. One experienced Northwest contractor estimated that his bid per acre would be 20 percent less in a 2,000-ton contract involving 9,200 acres than in a 100-ton contract involving 460 acres.

In the economic analyses that follow, an average initial treatment cost of $60 per acre will be used. This approximates the cost of applying 200 pounds of nitrogen per acre in the form of 435 pounds of urea fertilizer on 7,400 acres of the

Willamette National Forest in 1976. To illustrate the effects of a lower initial cost, a $40 per acre treatment cost will also be used.

INTEREST CHARGES

The compound interest costs of carrying the initial investment strongly affect profits gained from fertilization and other intensive management practices. As consumers, we know that such carrying charges are based on interest rate and duration of the loan. Although the market rate of interest may be 12 percent, the real rate of interest is less because the rate of inflation must be subtracted from it. For example, if one borrows money at the market rate of 12 percent and the annual rate of inflation is 5 percent, then the real rate of interest is only 7 percent.

During a 10-year period, a fertilization cost of $60 borrowed at a real rate of 7 percent almost doubles to a cost of $118 (fig. 5). If carried 20 years, it doubles again to $232 or almost four times the initial cost. Therefore, to break even, the increase in value of wood harvested from the fertilized stand must equal $118 if harvested in 10 years and $232 if harvested in 20 years.

In the economic analyses that follow, we selected 10 and 20 years as investment periods. We assumed that most of the volume gained from fertilization would be accumulated in 10 years and that this extra volume could be cut and sold at that

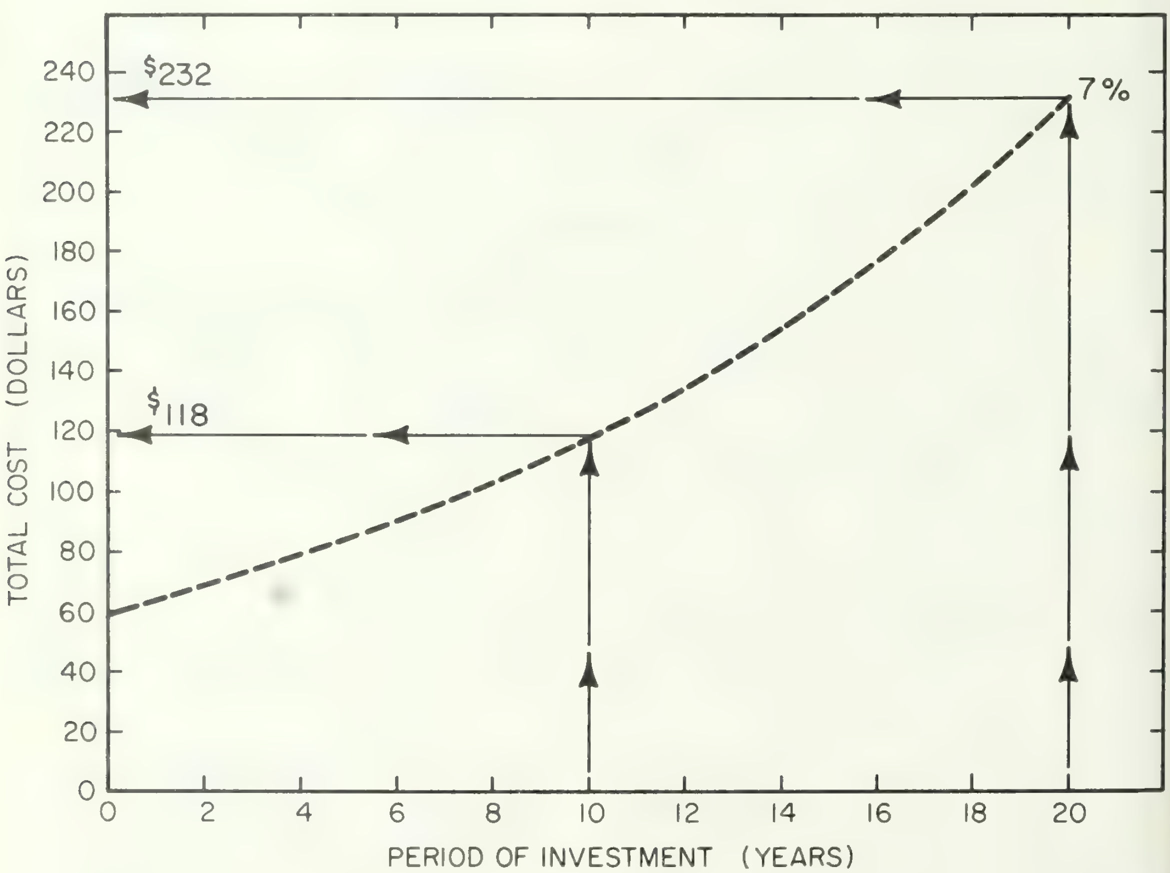

Figure 5.--Cumulative cost of fertilizing based on an initial cost of $60 per acre compounded at 7 percent interest.

time. But harvesting trees 10 years after treatment is only reasonable if fertilizer is applied to a stand that is merchantable or nearly merchantable. If smaller trees are fertilized, then a longer investment period is necessary until crop trees reach merchantable size.

Figure 6 shows the total cost of fertilization when initial costs of $60 and $40 per acre are compounded at 7-percent interest. Notice that the total or cumulative cost for a $60 initial cost is 1-1/2 times that for a $40 initial cost.

Revenue

The land manager who invests in forest fertilization anticipates increased growth and, therefore, increased revenue from his forest. Investment is profitable when the increased revenue exceeds the attendant costs.

VOLUME GAINED

The extra wood attributable to fertilization increases revenue when it is harvested and sold. The additional revenue gained from fertilization depends on the amount of extra volume and its price per unit. For the landowner who sells only stumpage, this extra revenue is obtained from having more volume to sell. For landowners with manufacturing facilities, however, additional revenue can accrue because this extra volume may reduce a need to purchase higher-priced wood on the open market.

The extra volume of wood gained from fertilization and how soon this

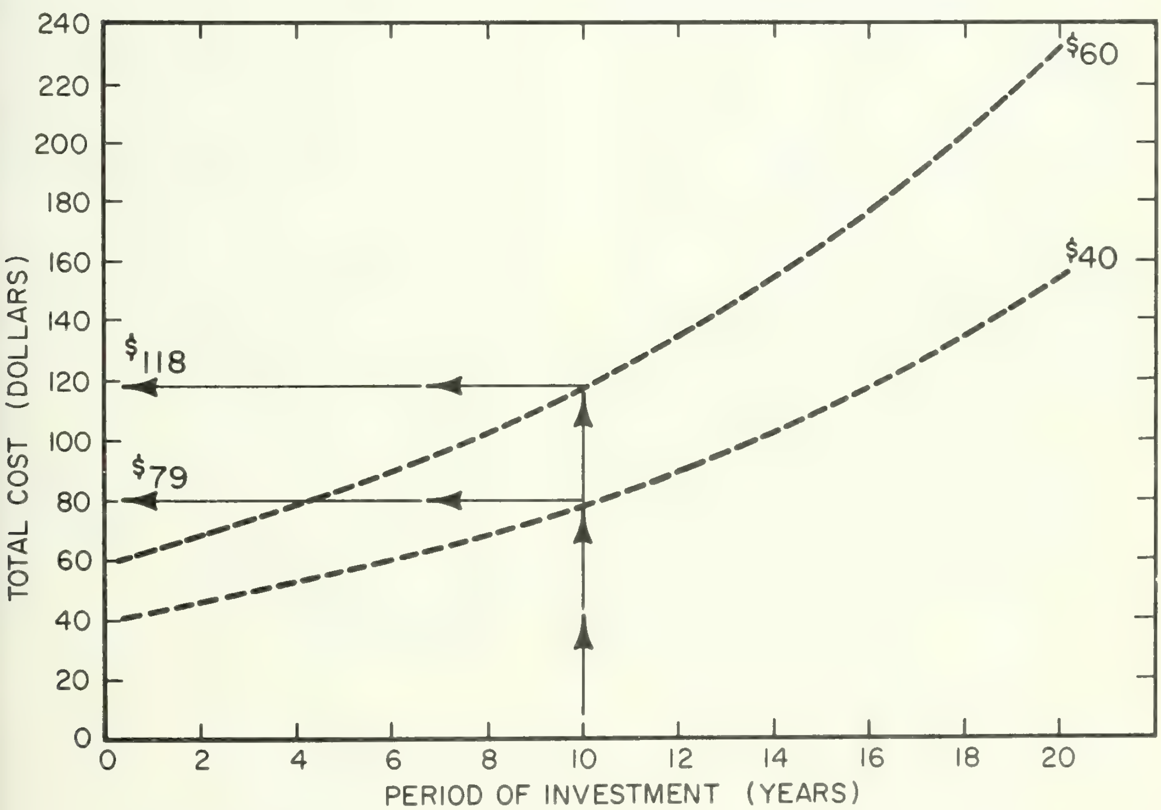

Figure 6.--Cumulative costs of fertilizing based on initial costs of $40 and $60 per acre compounded at 7-percent interest.

wood can be harvested strongly affect the revenue gained from the investment. Where natural productivity is restricted by nutrient deficiencies, fertilizers not only increase usable yields, but also enable land managers to make earlier commercial thinnings and final harvests.

In Part I, we described the effects of nitrogen fertilizer on growth of Douglas-fir. Experimental trials indicated that land managers can reasonably expect from 200 to 800 additional cubic feet of stemwood per acre over a 10-year period after applying 150 to 200 pounds of nitrogen per acre. Moreover, the cubic foot gains in total stem volume were more on sites of low natural productivity than on sites of high natural productivity (table 2).

STUMPAGE PRICE

The stumpage price paid to the forest owner is the residual or net value after the costs of logging, loading, and hauling are subtracted from the price paid for logs at the mill, which is the usual delivery point. Large trees have more stumpage value because the price paid at the mill increases while the costs of harvesting decrease (Worthington and Staebler 1961, Adams 1965, Adams 1967, Worthington 1966). Therefore, the landowner receives a higher stumpage price for selling larger trees (table 5).

Although growth is more precisely measured in cubic feet, cubic-foot prices are seldom used. To estimate the stumpage value of extra cubic feet produced after fertilization, one must convert *conventional* stumpage prices per thousand board feet, Scribner scale, to a price per cubic foot (Fahey and Woodfin 1976).[4/]

The number of board feet recoverable from a cubic foot of wood and the price per board foot are both strongly dependent upon tree size (table 6). Therefore, the price paid per cubic foot is higher for large diameter logs than for small logs. This difference in pricing means that a 300-cubic foot gain per acre from fertilization might return two times as much stumpage revenue to the landowner if he harvested 16-inch trees instead of 8-inch trees.

The extra wood produced from fertilization will be harvested years after this treatment is applied. To compute financial gains from treatment, one can estimate the future price of this extra wood by selecting an appropriate current stumpage price and projecting an annual rate of price increase. The average price for Douglas-fir stumpage on National

[4/] To convert stumpage values in board feet (BF) to cubic feet (CF):

$$\frac{\$}{CF} = \frac{\$}{BF} \times \frac{BF}{CF}$$

Table 5--Estimated prices and costs in 1976 by average tree diameter

Average d.b.h.	Mill price	Logging and hauling costs	Stumpage price
Inches	Dollars per thousand board feet, Scribner		
[1/]8	180	90	90
[1/]12	190	80	110
16	200	60	140
20	210	50	160
30	215	50	165

[1/] Frequently bought and sold on a tonnage basis.

Table 6--1976 stumpage prices in board feet and cubic feet

D.b.h. of harvested trees	Stumpage price per thousand board feet	Assumed conversion (board foot per cubic foot)	Stumpage price per cubic foot
Inches	Dollars		Dollars
8	90	2.8	0.25
12	110	3.8	.42
16	140	4.3	.60
20	160	5.0	.80
30	165	5.3	.87

Forests in western Washington and Oregon has increased substantially over the last decade. Even when prices are converted to constant dollars to remove general inflation, a substantial increase in real price is evident (table 7). Based on these regional prices and long-term lumber prices nationally, we assumed a 2-percent annual increase in the real value of stumpage. This is probably a conservative estimate of the long-term trend.

Table 7--Average stumpage prices for old- and young-growth Douglas-fir by year

Year	Stumpage price	
	Actual[1/]	1976 dollars[2/]
	Dollars per thousand board feet	
1965	43	78
1966	50	88
1967	42	72
1968	61	100
1969	82	127
1970	42	62
1971	49	69
1972	72	98
1973	138	177
1974	202	233
1975	170	180
1976	176	176

1/ Prices paid to USDA Forest Service, Region 6. Source: Ruderman 1977.

2/ Converted to 1976 dollars using consumers price index.

For our analysis, we want to ignore general inflation because it reduces the purchasing power of the dollar by an amount that offsets the increases in revenue. One can readily see, however, that a long-term increase in the price of wood which exceeds general inflation will increase the attractiveness of investments that produce more wood. Therefore, these increases in the real price of wood must be included in an economic analysis.

We consider two ways to accommodate increases in real price. If we included them by projecting current prices at a 2-percent rate of increase, we would have stumpage prices that differed every year. To avoid this inconvenience, we lowered the interest rate on the fertilization investment to adjust for the expected 2-percent increase in the real price of wood. Consequently, we could use today's prices in our analyses. Notice that "today's prices" means current stumpage prices at the time you are performing an economic analysis.

Our procedure is simply a second reduction in interest rates. Recall that we first adjusted market rates of interest to real rates of interest to remove the general effects of inflation. We now calculate an effective rate of interest to incorporate the rate of increase in the real price

of wood. By simple subtraction, we reduce the real rate of interest by the rate of increase in the real price of wood.[5/] In our example, the real rate of interest is 7 percent and the rate of real price increase is 2 percent; therefore, the effective rate of interest is 5 percent. Cumulative costs based on other effective rates of interest are provided (Appendix A).

Using an effective rate of interest will make it easier to compare fertilizer investments. Notice, however, that this effective rate of interest does not show the full return on the investment. The full return from the fertilizer investment has two components: the increased volume of wood and the increase in the real price of that extra wood. Therefore, the full return on investment for our break-even analysis is 5 percent plus 2 percent, or 7 percent.

To compare this full rate of return from a fertilization investment with other investments such as stocks and bonds, one must subtract the expected rate of inflation from the market rate of return of stocks and bonds. For example, with inflation estimated at 6 percent, a bond yielding a 10-percent market rate has a net rate of 4 percent compared to the 7 percent of our break-even analysis.

We get a lower cumulative cost when we use an effective rate of interest to project treatment costs. This is an adjusted cost (fig. 7).

[5/] Although this is not precisely correct (Flick 1976), the bias is negligible in the range of interest rates relevant to this kind of analysis.

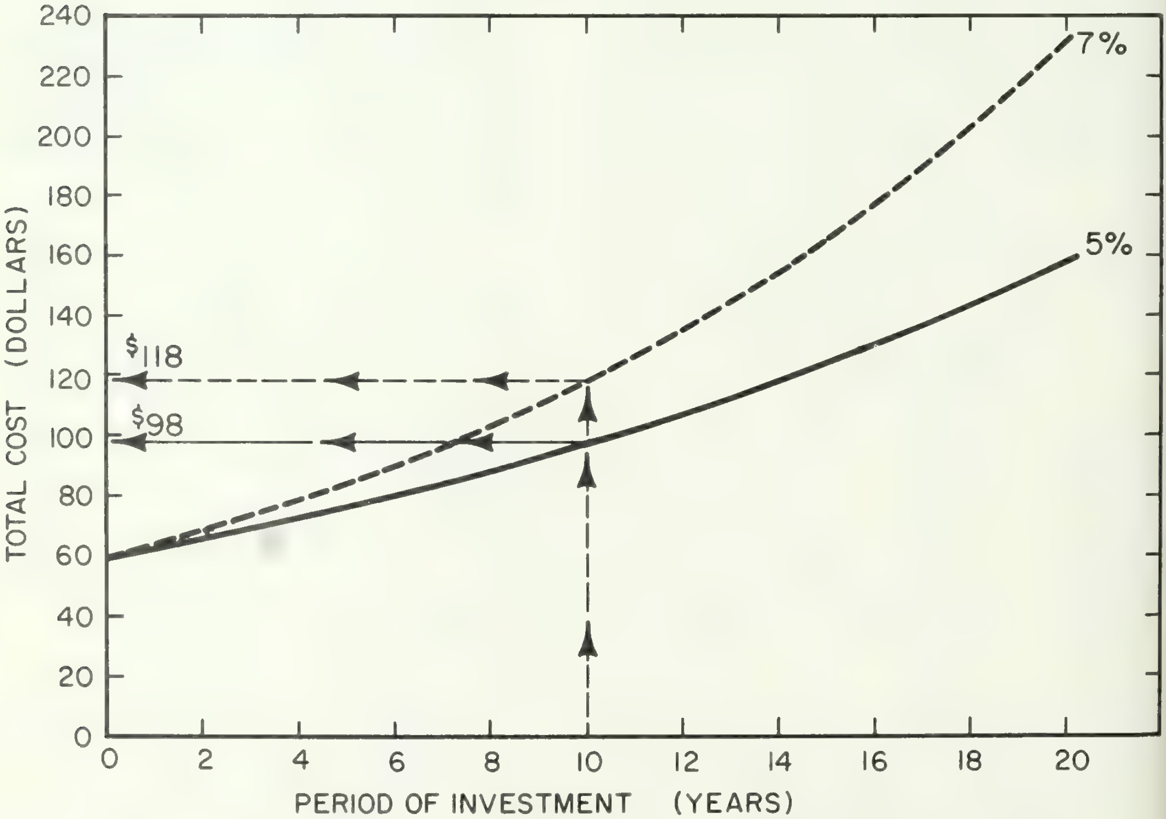

Figure 7.--Cumulative costs of fertilizing based on an initial cost of $60 per acre compounded at 5- and 7-percent interest.

The broken line shows a $60 treatment cost that became a cost of $118 after 10 years. The solid line shows that a $60 treatment cost expands to an adjusted cost of $98. When we use the effective rate of interest, we have automatically incorporated our assumed 2-percent annual increase in the real price of wood. In effect, we have offset part of the cumulative cost of fertilization by the anticipated increase in the real price of wood.

Revenue Required to Break Even

Now we will put these economic definitions and principles into practice by answering some practical questions about the economics of forest fertilization. Appendix B includes a sample worksheet supporting some of these examples and a blank form that can be used for other analyses. You will see what combinations of stumpage prices and extra yields will provide a break-even return from a specified investment in forest fertilization. We have a break-even situation if we specify in our analysis that the revenue should equal the total costs. A profit, however, is indicated if anticipated revenue exceeds the break-even revenue. One can estimate this profit by using more complex methods of economic analysis (Regional Forest Nutrition Project 1975a, 1977).

WHAT BREAK-EVEN VOLUME?

What extra volume from fertilization is necessary to break even? The curving line in figure 8 shows the various combinations of stumpage prices and volumes that will produce a $98 revenue. Recall from figure 7 that a $60 initial cost compounded at 5-percent effective interest rate for 10 years equaled $98.

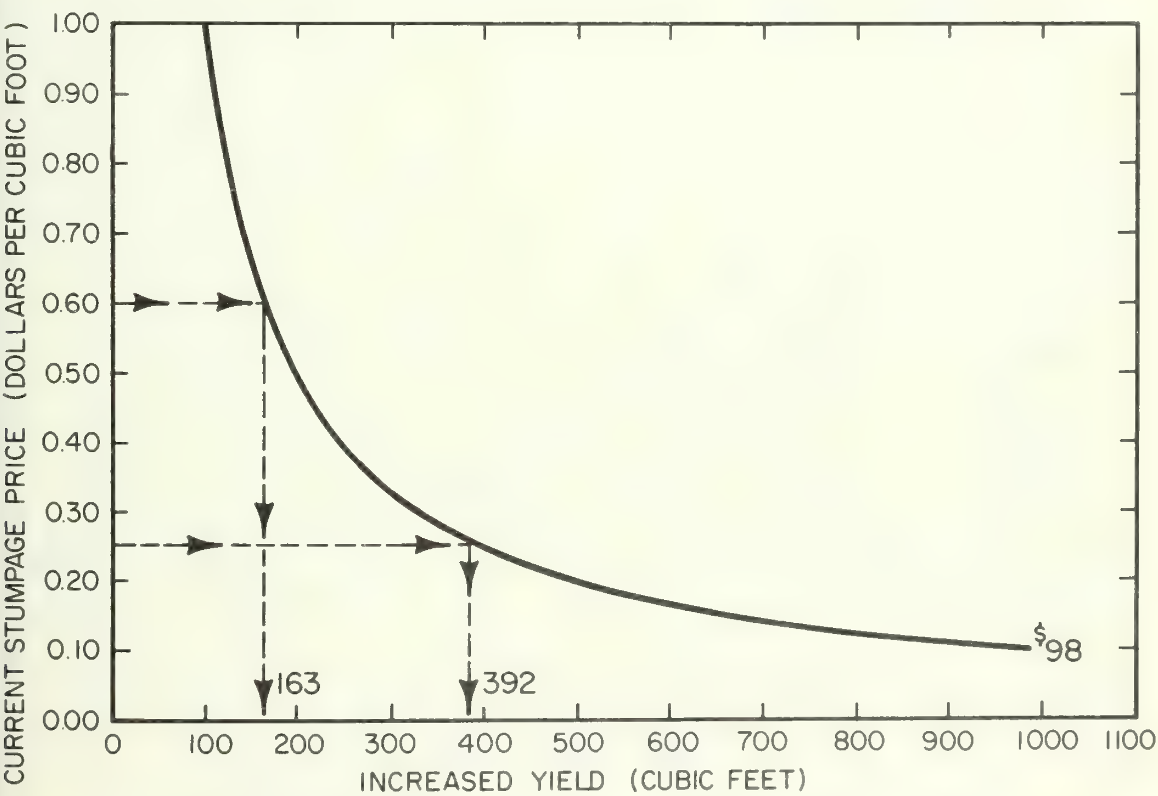

Figure 8.--Price-quantity combinations to offset a $98 per acre cumulative cost of fertilizing.

Notice that the amount of extra volume needed to break even depends on the stumpage price; lesser volumes are needed when stumpage prices are high.

For example, stumpage price for trees averaging 8-inch d.b.h. at harvest was estimated at 25 cents per cubic foot and for trees averaging 16-inch d.b.h. was 60 cents (table 6). Using these stumpage prices, we see that the break-even volume from 8-inch trees is 392 cubic feet and 163 cubic feet if harvested from 16-inch trees (fig. 8). This clearly illustrates the economic advantage of increasing growth of larger trees and harvesting gains from larger trees.

Lower initial costs of treatment reduce the break-even volume. As discussed previously, several factors can lower initial cost of treatment. These include fertilizing large contiguous acreages, applying lesser amounts of fertilizer, or negotiating a contract when the demand for fertilizer or applicators is low. Assume that initial cost can be reduced from $60 per acre to $40. Whereas the $60 cost increases to $98 after 10 years, the $40 cost increases to only $65, as shown by the broken line (fig. 9). Therefore, a lesser volume will cover these reduced cumulative costs. For example, assuming a current stumpage price of 60 cents per cubic foot, 108 additional cubic feet would be necessary to offset a $40 treatment cost, compared to 163 cubic feet to offset a $60 initial cost.

Finally, by lowering the carrying charges, one can reduce the break-even volume. Fertilizing mature trees is one way to do this, because commercial thinning or final harvests

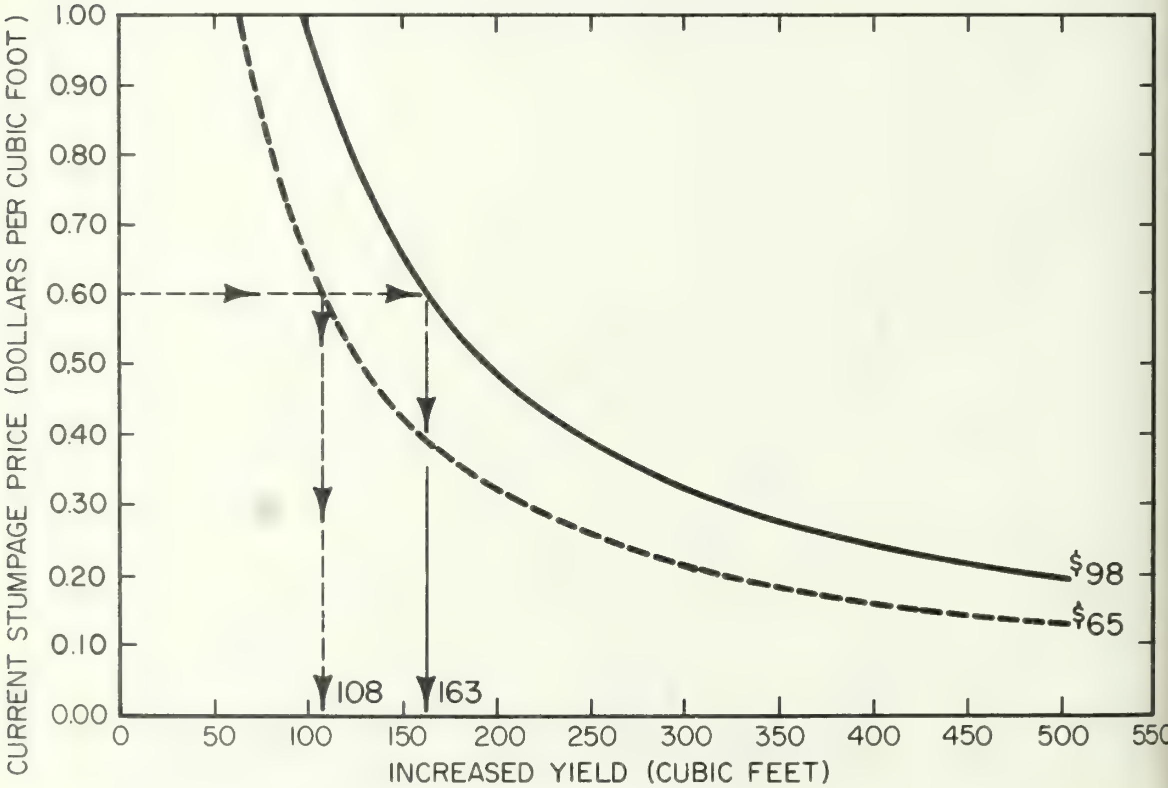

Figure 9.--Volume necessary to offset $65 and $98 cumulative costs at specified stumpage price, per acre basis.

can remove extra volume within 5 to 10 years after fertilization. In figure 10, the solid, curving line again indicates the $98 revenue necessary to cover a $60 treatment cost when carried for 10 years at 5-percent compound interest. If harvest is delayed for 20 years after fertilization, however, this initial cost expands to $159. Therefore, more volume is necessary to break even.

For example, if we fertilize a stand averaging 6-inch d.b.h. and waited 10 years until crop trees averaged 8 inches with an estimated stumpage value of 25 cents per cubic foot, we would need 392 cubic feet to break even (fig. 10). Now compare this volume to the 636 cubic feet necessary for another land manager who fertilizes 3-inch trees and must wait 20 years for the increase to be harvested from 8-inch trees. Doubling the investment period increases the total cost from $98 to $159 per acre. Therefore, 636 cubic feet instead of 392 would be necessary to break even.

WHAT BREAK-EVEN PRICE?

Now, let us use these same curves in a different way. Based on existing data from fertilized stands (table 3), some managers can estimate the amount of extra volume they expect from fertilizing a specific stand. Therefore, they can judge the economic feasibility of fertilization by determining the current stumpage price needed to break even.

The same procedure used to estimate break-even *volume* can also be used to find the break-even *price*. First,

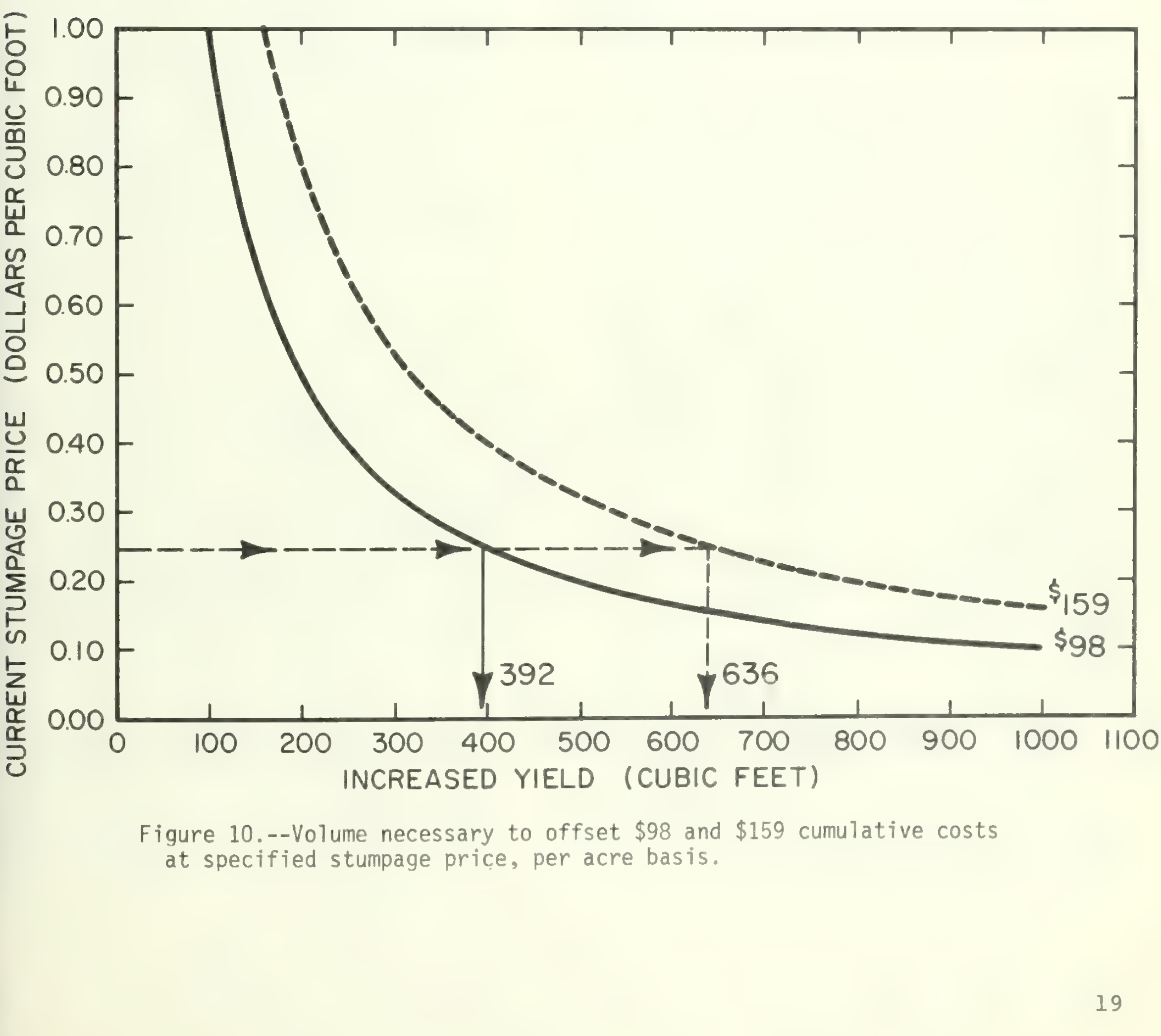

Figure 10.--Volume necessary to offset $98 and $159 cumulative costs at specified stumpage price, per acre basis.

estimate the gain in salable volume from fertilization and the years between fertilization and harvest, i.e., the period of investment. Second, determine the total cost of fertilization for a specified initial cost and the estimated period of investment. Third, use the graph of price-quantity combinations to estimate the current stumpage price necessary to offset this cumulative cost. If this estimated stumpage price is less than would be anticipated for the current market, then the break-even price is exceeded and a profit is indicated. An example will clarify this.

Assume a harvest of 500 cubic feet per acre 10 years after fertilization. An initial treatment cost of $60 per acre will expand to a total cost of $98 in 10 years. Therefore, a stumpage price of 20 cents per cubic foot would be necessary to offset this cumulative cost (fig. 11). A profit is indicated if current stumpage price exceeds 20 cents per cubic foot (the break-even price).

The preceding examples can be verified using the worksheet (Appendix B), the table of multipliers (Appendix A), and the graph of price-quantity combinations (Appendix C). Reworking these examples will check your understanding of the procedure before solving other problems of your choosing. A worksheet with data inserted from some of the sample problems is included as well as a blank form for solving other problems.

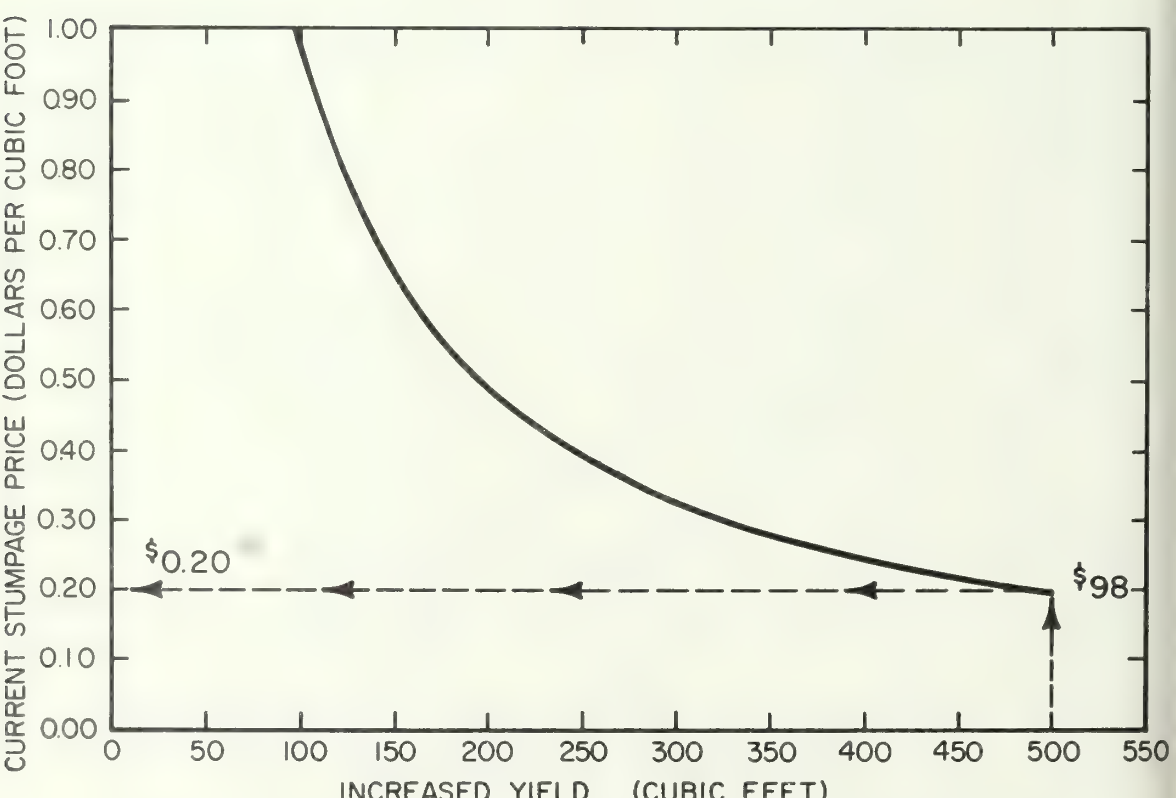

Figure 11.--Stumpage price necessary to offset a $98 per acre cumulative cost of fertilizing when expected gain in volume is 500 cubic feet per acre.

Other Financial Considerations

The effect of income taxes, the timing of cash flow, and other factors to be included in investment decisions are discussed below.

EFFECT OF INCOME TAXES

Our previous discussion and examples were directed toward obtaining a break-even analysis on a before-tax basis. Forestry and nonforestry investments should, however, be compared on a before- and after-tax basis. Net income from the timber sale will ordinarily be taxed as a capital gain rather than as ordinary income. This reduces the tax effect, because part of the income is tax exempt. Thus, the effect of taxation on forestry investments is often less than it is on most other investments.

Costs and revenues could be entered on the accompanying worksheet on an after-tax basis by adjusting them for tax effects. The result would be a break-even analysis on an after-tax basis that could be compared to other investments on an after-tax basis. More detailed procedures for doing that, however, are beyond the scope of this report.

CASH FLOW MANAGEMENT

As anyone with a checking account and financial obligations knows, cash flow management requires some attention. Negative balances are not tolerated for long and penalty costs are associated with them. Cash flow management by forest landowners poses similar problems. Some landowners have ready access to outside sources of investment capital while others do not. Those without ready access to capital must pay particular attention to cash flow management. Even those with ready access to capital must manage cash flows carefully, because the cost of borrowing capital is usually higher when it comes from outside sources. For most landowners, financing new investments out of accumulated savings or current income is probably the least costly method of financing. Therefore, forest landowners should consider timing receipts from timber harvest to provide cash needed for investments like fertilization. In some circumstances, altering the timing of commercial thinning or final harvest to coincide with needs for cash may be the most attractive method of financing.

CASH FLOW EFFECTS

Our economic analysis relates to fertilizing a specific stand of trees. Costs are incurred when a stand is fertilized. Subsequently, interest charges accrue on this investment. Revenue is received when the fertilized stand is thinned or harvested. This sequence of activities closely approximates the cash flow that results from fertilization investments for many private and some public forest managers. The effect of fertilization on the cash flow from some forests, however, may be very different.

On most public lands, the policy is to provide a non-declining flow of wood from the forest. This policy makes current harvests sensitive to current and future growth rates.

Mature or overmature stands in the forest inventory provide flexibility to harvest immediately extra growth gained from treating immature stands. For example, when growth is increased by fertilizing young stands, the harvest and resulting cash flow from mature stands may increase immediately. The increase in current harvest that occurs before any treated stands are actually harvested is called the "allowable cut effect" (Schweitzer et al. 1972).

It is widely recognized that the allowable cut effect occurs. It is also widely recognized that the immediate increase in current harvest and cash flow is the result of increasing the growth on future stands. Clearly, this immediate increase in cash flow does not come directly from the sale of wood that is produced by the fertilizer. Yet, through the allowable cut effect,

fertilization can increase harvest level and cash flow.

Understandably, there is disagreement and controversy over the consideration that should be given to this immediate cash flow increase in ranking alternative investments in forest management (Lundgren 1973, Teeguarden 1973). Furthermore, the magnitude of the allowable cut effect does not have a predictable relationship to the increases in future growth (Bell 1976). The allowable cut effect can be reliably estimated only by making a series of allowable harvest calculations and then comparing them. Because of these limitations, it is probably unsafe to consider the allowable cut effect in investment decisions without the counsel of someone knowledgeable in the economic theory that supports benefit-cost analysis. The immediate increase in cash flow, however, that would accompany a fertilization program is a consequence that decisionmakers should recognize.

Summary

The seven major points of Part II follow:

1. The total costs of fertilization include the initial costs of fertilizing and the interest charges on this investment.

2. Because of the nature of compound interest charges, fertilizing stands that will be harvested in 10 years will generally be more profitable than fertilizing stands that will be harvested after a longer investment period.

3. Because larger trees bring a higher price than smaller trees, fertilizing larger trees will generally be more profitable than treating smaller trees on sites of equal productivity.

4. Because of the greater growth increases reported for low-quality sites after fertilization, fertilizing trees on these poorer sites will generally be more profitable than treating trees of the same size on sites of higher natural productivity. More precise statements about setting priorities among stands for fertilization require more detailed information and analysis.

5. A projected long-term increase in the price of wood which exceeds general inflation will increase the attractiveness of fertilization and other investments that produce more wood.

6. Timing of receipts from timber harvests to coincide with cash needs for fertilization will often be the least costly method of financing.

7. Fertilization can be an economically attractive way to increase wood production of Douglas-fir forests.

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Appendix A

Multiplier to convert initial cost to total cost[1/]

Years	Effective rates of interest — percent						
	3	4	5	6	7	8	9
5	1.16	1.22	1.28	1.34	1.40	1.47	1.54
6	1.19	1.27	1.34	1.42	1.50	1.59	1.68
7	1.23	1.32	1.41	1.50	1.61	1.71	1.83
8	1.27	1.37	1.48	1.59	1.72	1.85	1.99
9	1.30	1.42	1.55	1.69	1.84	2.00	2.17
10	1.34	1.48	1.63	1.79	1.97	2.16	2.37
11	1.38	1.54	1.71	1.90	2.10	2.33	2.58
12	1.43	1.60	1.80	2.01	2.25	2.52	2.81
13	1.47	1.67	1.89	2.13	2.41	2.72	3.03
14	1.51	1.73	1.98	2.26	2.58	2.94	3.34
15	1.56	1.80	2.08	2.40	2.76	3.17	3.64
16	1.60	1.87	2.18	2.54	2.95	3.43	3.97
17	1.65	1.95	2.29	2.69	3.16	3.70	4.33
18	1.70	2.03	2.41	2.85	3.38	4.00	4.72
19	1.75	2.11	2.53	3.03	3.62	4.32	5.14
20	1.81	2.19	2.65	3.21	3.87	4.66	5.60

[1/] Example: Assuming (1) initial cost of fertilizer = $60, (2) an investment period = 10 years, (3) an effective rate of interest = 5 percent, then total cost = $60 X 1.63 = $97.80.

Appendix B

Worksheet for determining break-even volume or stumpage price

Known or assumed

1. Initial cost of fertilizing — $ 60 per acre
2. Years to next commercial cut — 10 years
3. Average d.b.h. of trees to be harvested — 8 inches
4. Market rate of interest — 12 percent
5. Rate of inflation — 5 percent
6. Rate of increase in real price of stumpage — 2 percent

Compute or determine

7. Effective rate of interest (Item 4 - Item 5 - Item 6) — 5 percent
8. Cumulative cost of fertilizing (Item 1 X multiplier from Appendix A) — $ 98 per acre
9. Break-even volume
   - A. Assumed stumpage price (Table 6 or supply your own) — $ .25 per cubic foot
   - B. Volume needed to break even (Read from Appendix C or item 8 ÷ item 9A) — 392 cubic feet per acre
10. Break-even price
   - A. Assumed volume gain (Tables 2 and 3 or supply your own) — 500 cubic feet per acre
   - B. Stumpage price needed to break even (Read from Appendix C or item 8 ÷ item 10A) — $ .20 per cubic foot

Worksheet for determining break-even volume or stumpage price

Known or assumed

1.	Initial cost of fertilizing	$______per acre
2.	Years to next commercial cut	______years
3.	Average d.b.h. of trees to be harvested	______inches
4.	Market rate of interest	______percent
5.	Rate of inflation	______percent
6.	Rate of increase in real price of stumpage	______percent

Compute or determine

7.	Effective rate of interest (Item 4 - Item 5 - Item 6)	______percent
8.	Cumulative cost of fertilizing (Item 1 X multiplier from Appendix A)	$______per acre
9.	Break-even volume	
	A. Assumed stumpage price (Table 6 or supply your own)	$______per cubic foot
	B. Volume needed to break even (Read from Appendix C or item 8 ÷ item 9A)	______cubic feet per acre
10.	Break-even price	
	A. Assumed volume gain (Tables 2 and 3 or supply your own)	______cubic feet per acre
	B. Stumpage price needed to break even (Read from Appendix C or item 8 ÷ item 10A)	$______per cubic foot

Appendix C

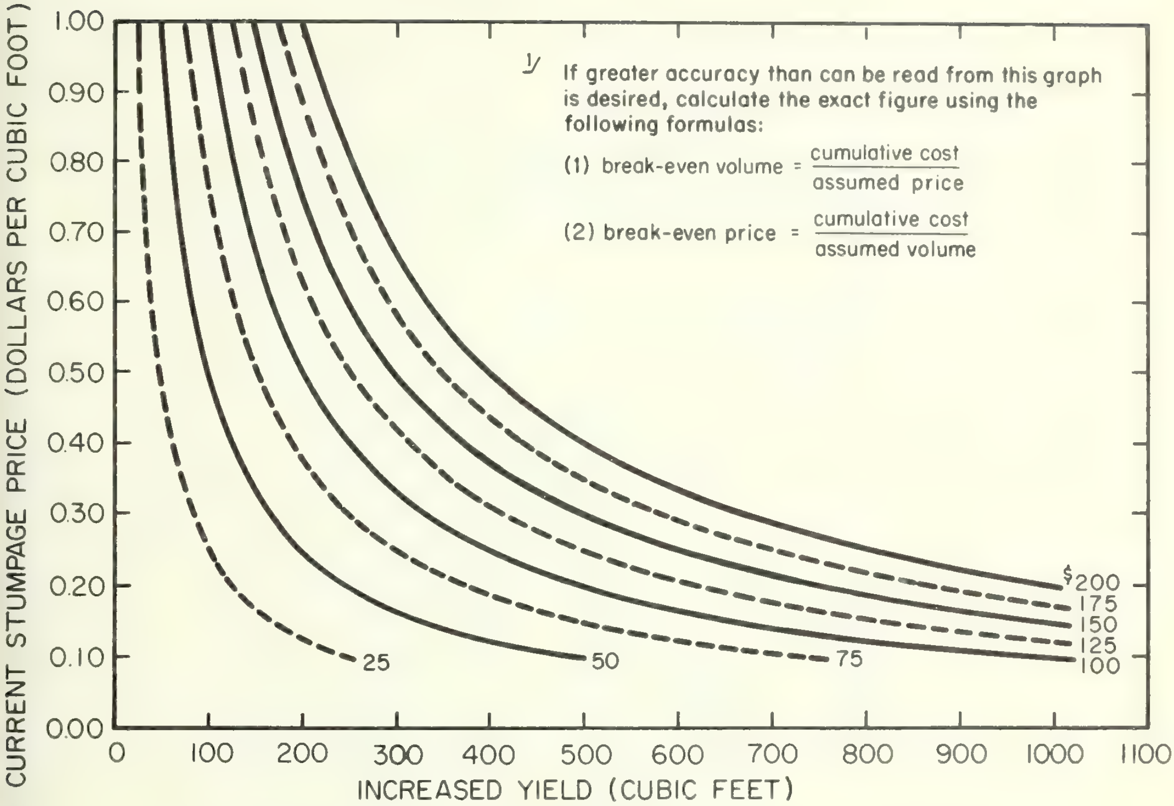

Figure 12.--Price-quantity combinations to offset specified cumulative costs of fertilizing, per acre basis.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

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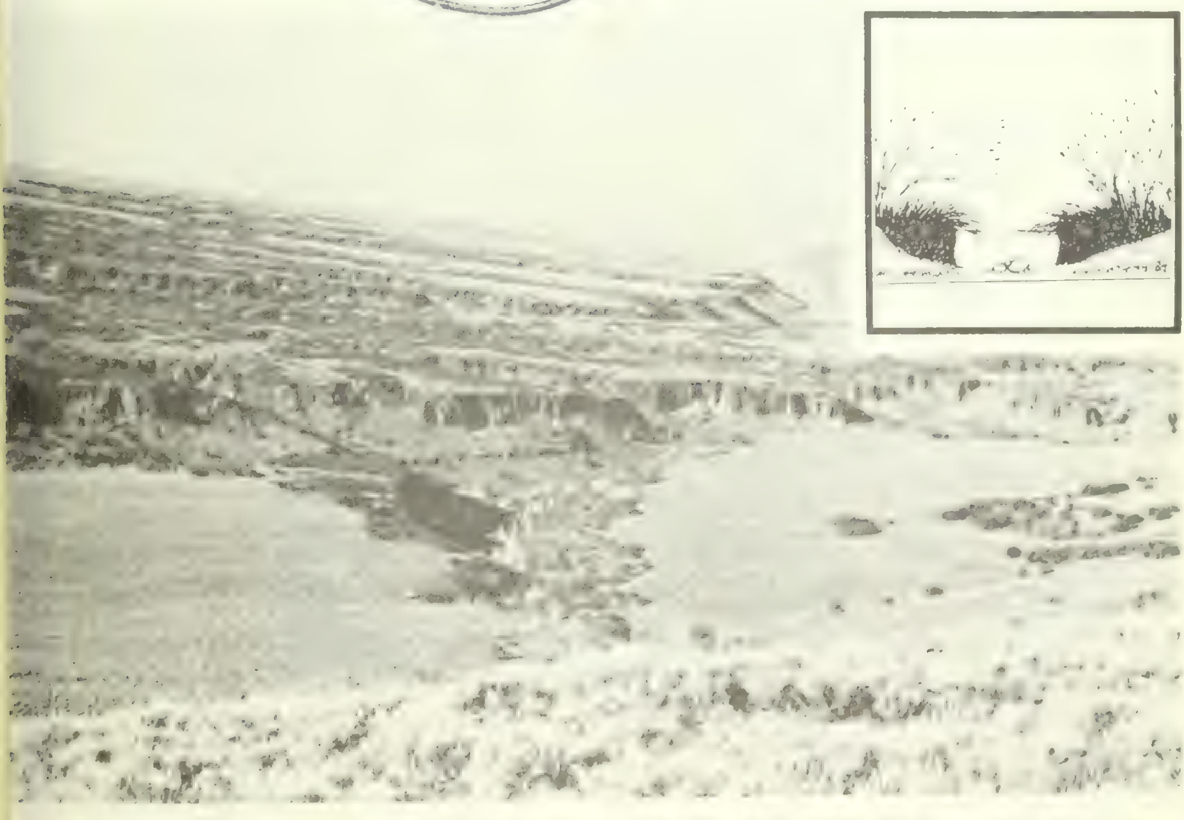
GENERAL TECHNICAL REPORT PNW-84
1979

WILDLIFE HABITATS IN MANAGED RANGELANDS-- THE GREAT BASIN OF SOUTHEASTERN OREGON

NATIVE TROUT

WAYNE BOWERS
BILL HOSFORD
ART OAKLEY
CARL BOND



PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

ABSTRACT

All land management activities on managed rangelands will have some impact(s) on fish habitat; those in the riparian zone will have the greatest impact(s). Native trout populations in the Great Basin of southeastern Oregon exhibit predictable responses to alterations in their habitats; optimum production of native trout is therefore achievable through careful habitat management.

KEYWORDS: Fish habitat, trout, range management.

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This publication is part of the series **ildlife Habitats in Managed Rangelands — he Great Basin of Southeastern Oregon**. The rpose of the series is to provide a range anager with the necessary information on ildlife and its relationship to habitat condi- ons in managed rangelands in order that the anager may make fully informed decisions.

The information in this series is specific to e Great Basin of Southeastern Oregon and is nerally applicable to the shrub-steppe areas the Western United States. The principles d processes described, however, are gener- ly applicable to all managed rangelands. The rpose of the series is to provide specific in- rmation for a particular area but in doing so develop a process for considering the welfare wildlife when range management decisions e made.

The series is composed of 14 separate blications designed to form a comprehensive ole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.

Introduction

Southeastern Oregon has a variety of fish habitats which include major rivers, tributary streams, large and small reservoirs, lakes, and springs. These habitats are directly related to and highly dependent on the conditions of the surrounding rangeland watersheds. Satterlund (1975, p. 22) put it this way: "Rangelands may yield little water, but they are second only to cultivated lands as a source of water quality problems." It may be fairly stated, therefore, that man's agricultural activities in rangelands of southeastern Oregon have altered aquatic habitats more than any other land use. And of all the agriculturally oriented activities in southeastern Oregon rangelands, livestock grazing has exerted greater influence on more aquatic habitats than any other land use (Anderson 1968, Marcuson 1977). Gebhards (1970, p. 3) summed it up:

> Man has gained the knowledge and technical skill that makes him capable of completely altering, or nullifying natures handiwork—but he rarely ponders his inability to duplicate it.
>
> ...Today, through the science of hydrology we know that a stream is in reality the end product of a watershed. Water originating as precipitation flows across and through the surface of the watershed to form the stream. Changes brought about in the watershed by...road construction, overgrazing by livestock, or other disturbances of the land, can greatly alter the pattern of water movement and even water quality within the watershed.

Thirty-eight species of fish are known to occur in southeastern Oregon (Bond 1973) (table 1). Some of these species, including trout (*Salmo* spp.), were once native to most streams. If habitat conditions are or become suitable for good trout production, populations of other indigenous cold-water fish, such as sculpins (*Cottus* spp.), mountain whitefish (*Prosopium williamsoni*), and some suckers (*Catostomus* spp.), will also thrive because their basic habitat requirements are similar (table 2).

Some species, such as bass (*Micropterus* spp.), crappie (*Pomoxis* spp.), and catfish (*Ictalurus* spp.), have been introduced and provide good fisheries. Introduced fish either have occupied habitats which have been altered in a way that favors their living requirements or have occupied natural habitats that are suitable to them but unsuitable or marginal for trout. Introduced species may also partially displace native non-game species, and may pose a threat to sensitive species.

Annual stocking programs have also developed important fisheries in some reservoirs and specific sections of streams. Although such stocking programs will continue to be important, the production of native trout in hundreds of kilometers of streams is considered to be the highest priority and is emphasized in this chapter.

Table 1—Fishes that are known to occur in southeastern Oregon[1]

Trout and Salmon:	
Redband trout	*Salmo* species
Brown trout	*Salmo trutta*
Rainbow trout	*Salmo gairdneri*
Alvord cutthroat	*Salmo clarki* subspecies
Kokanee	*Oncorhynchus nerka*
Coho salmon	*Oncorhynchus kisutch*
Brook trout	*Salvelinus fontinalis*
Dolly Varden trout	*Salvelinus malma*
Mountain whitefish	*Prosopium williamsoni*
Sturgeons:	
White sturgeon	*Acipenser transmontanus*
Sunfishes:	
Smallmouth bass	*Micropterus dolomieui*
Largemouth bass	*Micropterus salmoides*
Warmouth bass	*Lepomis gulosus*
Bluegill	*Lepomis macrochirus*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
Perches:	
Yellow perch	*Perca flavescens*
Catfishes:	
Channel catfish	*Ictalurus punctatus*
Black bullhead	*Ictalurus melas*
Brown bullhead	*Ictalurus nebulosus*
Flathead catfish	*Pylodictus olivaris*
Tadpole madtom	*Noturus gyrinus*
Sculpins:	
Mottled sculpin	*Cottus bairdi semiscaber*
Torrent sculpin	*Cottus rhotheus*
Piute sculpin	*Cottus beldingi*
Shorthead sculpin	*Cottus confusus*
Minnows and Carp:	
Carp	*Cyprinus carpio*
Tui chub	*Gila bicolor*
Lahontan redside	*Richardsonius egregius*
Redside shiner	*Richardsonius balteatus balteatus* also *R. b. hydrophlox*
Longnose dace	*Rhinichthys cataractae dulcis*
Leopard dace	*Rhinichthys falcatus*
Speckled dace	*Rhinichthys osculus*
Chiselmouth	*Acrocheilus alutaceus*
Northern squawfish	*Ptychocheilus oregonensis*
Suckers:	
Largescale sucker	*Catostomus macrocheilus*
Bridgelip sucker	*Catostomus columbianus*
Lahontan sucker	*Catostomus tahoensis*
Mountain sucker	*Catostomus platyrhynchus*

[1]Bond, Carl E., 1974. Endangered plants and animals of Oregon. I. Freshwater fishes. Spec. Rep. 205 (revised), 9 p. Agric. Exp. Stn., Oreg. State Univ., Corvallis.

Table 2—Habitat requirements for fishes of southeastern Oregon. X = habitat(s) where species normally occurs, O = habitat(s) where species can be found

Species	Stream[1]						Large reservoir[3]	Small reservoir or Pond[4]	Lake	Spring
	Small		Medium		Large					
	Cold[2]	Warm	Cold	Warm	Cold	Warm				
Trout & Salmon										
Redband trout	X	O	X	O	X	O	O	O	O	O
Brown trout			X	O	X	O				
Rainbow trout	X	O	X	O	X	O	X	X	O	O
Alvord cutthroat	X	O	X	O						
Brook trout	X		X							X
Dolly Varden trout	X	O	X	O	X	O	O			
Kokanee						O	X			
Coho						O	X			
Mountain whitefish	X	O	X	O	X	O	O			
Sturgeons										
White sturgeon					X	O	O			
Sunfishes										
Smallmouth bass				X		X	X	O		
Largemouth bass				O		X	X	X	X	
Warmouth bass					O	X	X	X		
Bluegill				O		X	X	X	O	
White crappie				O		X	X	X	O	
Black crappie				O		X	X	X	O	
Perches										
Yellow perch				O		X	X	X	X	
Catfishes										
Channel catfish				O		X	X	O		
Black bullhead				O		X	X	X	O	
Brown bullhead				O		X	X	X	X	
Flathead catfish						X	X	O		
Tadpole madtom						X	O			
Sculpins										
Mottled sculpin	X	O	X	O	X	O			O	
Torrent sculpin	X	O	X	O						
Piute sculpin	O	O	X	O	O	O				
Shorthead sculpin	X	O	X	O						
Minnows										
Carp	O	O	O	X	O	X	X	O	O	
Tui chub		O		X		O	X	X	O	
Lahontan redside	X		X	O						
Redside shiner		X		X		X	X	O	O	
Longnose dace	O	O	X	O	X	O	O	O	O	
Leopard dace			X	X	O	O				
Speckled dace	X	X	X	X	X	X	O	O	O	X
Chiselmouth				X		X	X	O	O	
Northern squawfish				X		X	X	O	O	
Suckers										
Largescale sucker			O	X	O	X	X	O	O	
Bridgelip sucker	O	O	X	O	X	O	X	X	O	
Lahontan sucker	X		X	O						
Mountain sucker	X		X		O					

[1] Stream size is based on average width of water (wetted perimeter of streambed or channel) during the summer low-flow period.

Small = Less than 3.04 m (10 feet)
Medium = 3.4 to 7.6 m (11 to 25 feet)
Large = Greater than 7.6 m (25 feet), including main rivers, such as the Snake, Owyhee, and Malheur (lower parts of North and South forks) Rivers.

[2] Cold — Refers to streams with maximal summer water temperatures usually less than 21°C (70°F).
Warm — Refers to streams with maximal summer water temperatures commonly over 21°C (70°F).

[3] Reservoirs over 10.1 surface hectares (25 surface acres) in size and 4.5 m (15 feet) in depth at usual minimum level.

[4] Bodies of water less than 10.1 surface hectares (25 surface acres) in size and 3.04 m (10 feet) in depth at usual minimum level. Includes many small farm ponds.

Objectives

No long-term research has been specifically aimed at the factors affecting trout production in southeastern Oregon, but studies are available that define the habitat components necessary for good trout production, identify limiting factors, and describe land-use conflicts. Data specific to southeastern Oregon and applicable data from other areas are, therefore, synthesized to provide rangeland managers with the information necessary to make the best possible decisions with respect to fish habitat management. Our objectives are to present these data in a way that will assist managers in evaluating trade-offs while achieving short-term management goals, and to present a tool that can be used simultaneously in long-range land-use planning.

Assumptions

In order to fulfill the charge of this chapter it was necessary to recognize the following assumptions:

1. All land management activities will have some impact(s) on fish habitat. Those activities that affect the riparian zone will have the greatest impact.

2. Water quality and habitat conditions in downstream areas are directly affected by land management activities in upstream tributary systems.

3. Trout populations have predictable responses to changes in habitat conditions.

4. If trout habitat is optimal, life requirements of other cold-water species will generally be fulfilled.

5. Because of the increasing public interest in "wild trout," more intensive management of native trout and their habitats will be required in future years. Management will, therefore, be concentrated primarily in the medium- and small-sized tributary streams where most of these fish are found.

6. Because of increasing public concern for certain non-game fishes, land managers will also have to consider management activit that affect those species.

Stream Zones in Southeastern Oregon

Streams in southeastern Oregon generai originate in mountains ranging in elevati from 2 134 to 2 734 m (7,000 to 9,000 ft). streams descend from the mountains, th pass through three distinctive zones—bould floodway, pastoral—and may terminate in desert sump (fig. 1).

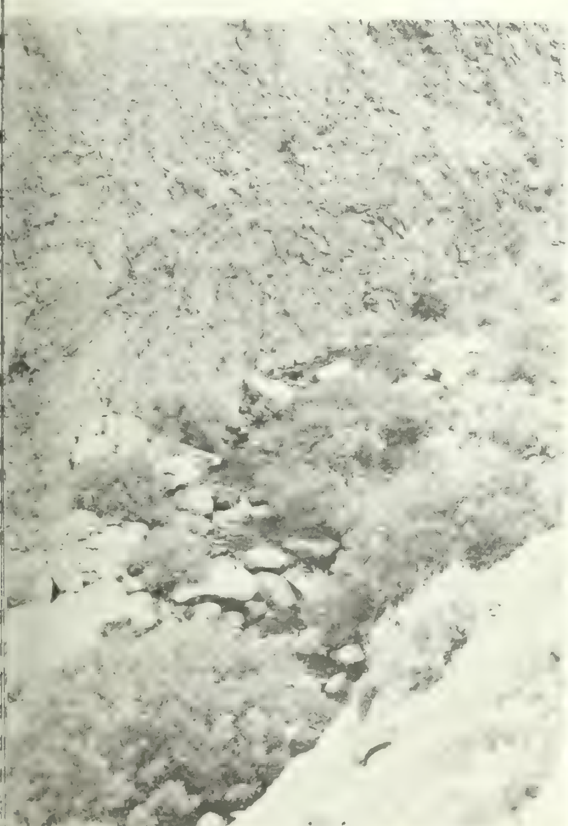
The upper reach of a stream, the bould zone or headwaters, normally has a ste gradient, falling at a rate of 7.6 m p kilometer (25 ft/mi) or more (fig. 2). This zone characterized by high velocity water wi coarse bedload material and a narrow chanı that goes through a steep-walled, bedro gorge. Vertical erosion of the channel mai tains a V-shaped valley.

The gradient gradually decreases as stream flows into the floodway zone, and the is a corresponding reduction in water veloci (fig. 3). A floodway zone is characterized by coarse, sand to baseball-sized, sediment lo which is constantly shifting, forming grav bars, islands, and new channels (Palmer 197 This zone forms floodplains along lar streams which are extensively used f agriculture.

In the pastoral zone, which includes t lower reach of a stream, the fine bedlo material, silt and sand, forms compact banks with a deeper meandering channel (fi 4). Stream banks are often steep and tree-line Water velocity is much reduced, and some the small streams disappear into the ground what is called a "desert sump" (fig. 5).

Undisturbed stream courses with den streamside vegetation, stable soils, aı moderate gradients—1 to 2 percent—ke water from rapidly descending a strea system. Streamside vegetation is importa since it stabilizes streambanks and the mov ment of sediments; this, in turn, gradual reduces the width of a stream and increases tl

Figure 1.—Graphic summary of stream channels of southeastern Oregon streams.



channel depth which creates better habitat conditions for trout (White and Brynildson 1967). Aquatic communities experience a minimum of disturbance where these conditions occur.

Where streamside vegetation is lacking, however, water temperatures rise because of increased exposure to solar radiation. An exposed rock formation, such as canyon walls or especially a bedrock stream bottom, acts as a heat sink that retains heat longer than does the surrounding habitat. Consequently, water temperatures, that would normally decrease rather rapidly after sundown, remain warm for a longer time, particularly on a hot day. Native desert trout can withstand a few hours of high water temperatures, but only if they can find relief in water of cooler temperatures sometime during the day. Where this is not possible,

Figure 2.—The boulder zone is the upper reach or headwaters of a stream which normally has a steep gradient and falls at a rate of 7.6 m per kilometer (25 ft/mi) or more. (Oregon Department of Fish and Wildlife photograph by Bill Hosford)

Figure 3.—In the floodway zone there is a gradual decrease in stream gradient and a corresponding reduction in water velocity. (Oregon Department of Fish and Wildlife photograph by Bill Hosford)

Figure 4.—In the pastoral zone the lower reach of a stream often has banks that are steep and tree-lined. (Oregon Department of Fish and Wildlife photograph by Bill Hosford)

Figure 5.—A desert sump is an area in the desert where a stream terminates and disappears into the ground. (Oregon Department of Fish and Wildlife photograph by Bill Hosford)

their available habitat may be severely restricted or they may be eliminated from a stream.

The best habitat conditions for trout production are generally in the lower boulder and upper floodway zones where water temperatures are cool and riffle-pool ratios are adequate (Elser 1968). As a stream approaches equilibrium in the lower floodway and pastoral zones, new meanders and channels are created. Water temperatures become high, siltation increases, and riffle-pool ratios decrease or are non-existent. Such habitat conditions are more suitable for production of warm-water species of fish than for trout.

Optimum Stream Conditions for Trout Habitat

Native species of trout, adapted to desert environments, have a remarkable ability to survive adverse conditions of high water temperatures, high alkalinities, unusually low streamflows, and marginal spawning areas. These conditions are not ideal and, consequently, trout populations are usually depressed.

If optimal habitat conditions for trout production are considered as management objectives, it should be recognized that not all of them can be achieved in every stream. Some streams, for example, may be too wide for streamside vegetation to provide canopy cover that adequately shades the surface of the water, and alternative management strategies will have to be considered.

The following habitat conditions are optimal for trout production in desert environments:

1. **Water Temperature.** Summer temperatures should not exceed 21°C (70°F). Certain strains of native trout can successfully survive water temperatures of 27°C (80.6°F) for short periods during the day and can also tolerate a 16° to 20°C (30° to 35°F) diurnal temperature fluctuation. Such extremes are not desirable.

2. **Stable Streambanks.** Stable non-eroding streambanks and watersheds are essential to protect spawning gravel, aquatic insects, trout eggs, and recently hatched fry from becoming suffocated by fine sediments, such as sand and silty material (Behnke and Zarn 1976). Acceptable streambanks have 80 percent or more of their total lineal distance in a stable condition.

3. **Streambed Sedimentation.** The riffle-rubble areas of streams are most important for food production and spawning (Cordone and Kelley 1961). At least 75 percent of the total riffle-rubble area in a stream should be free of siltation less than 0.8 mm (.03 in) in size. Furthermore, trout populations will be reduced if pools become filled with sediments which eliminate rearing or hiding areas.

4. **pH Range.** Most good desert trout waters have a pH between 6.5 and 9.0. Although some species of fish can tolerate a higher pH (10 to 10.5), this is not a desirable condition.

5. **Streamside Vegetation.** Streamside vegetation is the most important key in maintaining good trout habitat for several reasons:

a. Streamside vegetation is essential in providing shade which keeps water temperatures from becoming lethal during hot weather (Brown 1976). Such vegetation may consist of trees, shrubs, grasses, sedges or other plants. Streamside vegetation should shade at least 75 percent of the stream surface during the hours of 11 am to 4 pm from June to September, because solar radiation is highest during this time of day and season.

Topography, rocks, and canyon walls can provide some of this needed shade in some situations.

Streambank vegetation also acts as habitat for terrestrial insects which, when they fall into a stream, are an important food source for fish (Butler and Hawthorne 1968, Chapman 1966, Ellis and Gowing 1957, Meehan et al. 1977).

b. Streambank vegetative cov provides protection from erosion du ing periods of high water. Plant roo help hold soil in place. Stems an leaves bend with the water flo which reduces scouring and also ac as sediment traps. Sediment tra catch silt before it moves dow stream and settles on the more impo tant food-producing and spawnin areas of trout.

6. Instream cover is essential to trout f resting, protection from predators, and produ tion of food[1]. Various types of cover, such a boulders, provide instream habitat niche which act as a base for continual fish occ pancy. The trout carrying-capacity of a strean in otherwise good condition, is greatly reduce without adequate instream habitat niches.

Optimal instream cover should be availabl over at least 50 percent of the total strea area. Such cover may include rocks, turbule water in pools or riffles, debris, tree root overhanging banks, or aquatic vegetatio (Boussu 1954).

Overhanging streamside vegetation ma augment or replace instream cover provide such vegetation is not more than 60.8 ce timeters (2 ft) above the water. Overhangin vegetation should cover at least 50 percent o the streambanks and is particularly crucial o the outside bends of streams.

Effects of Livestock on Fish Habitat

Rangelands of southeastern Oregon hav been historically grazed by cattle (*Bos* sp.) horses (*Equus* sp.), and sheep (*Ovis* sp.). Muc of this activity was unrestricted and livestoc exceeded the carrying capacity of ranges caus ing severe range deterioration by 1900 (Head and Bartolome 1977, Foss 1960). Many of th

[1]Binns, Allen N., 1976. Evaluation of habitat quality i Wyoming trout streams. Unpublished paper presented a the Am. Fish Soc., Annu. Meet., Dearborn, Mich. 33 p.

uplands were denuded of soil-stabilizing plants which resulted in extensive sheet, rill, and gully erosion. Extensive down-cutting of stream channels on valley floors was also caused by heavy grazing[2] (Winegar 1977).

In many areas, especially during summer and early fall, riparian zones were extensively overused by livestock because of the lush plant growth and the proximity to water. Continued heavy livestock use of riparian zones produced the following results:

1. Compaction of soils due to livestock trampling caused a reduction of water infiltration, increased water runoff, and made successful reproduction difficult for many species of plants. This, along with a loss of ground cover, caused soil erosion throughout many watersheds.

2. Riparian vegetation needed to provide shade to streams was eliminated, and overhanging streambanks were broken down which resulted in loss of escape cover and accelerated bank erosion.

3. Some highly productive wet meadows have been lost because stream channels have eroded their way down, lowering the water table. This process has resulted in the encroachment of dry-site plant species, such as sagebrush (*Artemisia* spp.). Consequently, small streams that once had adequate flows during summer months are now intermittent or dry, creating a substantial loss of trout habitat.

4. Some streambottoms have been historically burned to eliminate dense vegetation and facilitate the gathering of livestock. This practice has been devastating to the entire riparian zone and associated fish habitat.

5. Coliform bacteria counts are extremely high in some streams due to livestock feces and carcasses. These materials not only impair water quality but also pose potential health problems for recreationists.

Studies have shown that in stream sections where livestock use is light or is eliminated by fencing, production of trout increases substantially. The average increase in fish production was 184 percent for five study areas[3] [4] (Gunderson 1968, Marcuson 1970, Lorz 1974) (fig. 6). These data indicate that trout production in streams currently being heavily grazed

[2]McKinley, Charles, 1965. The management of land and related water resources in Oregon—A case study in administrative federalism. p. 21-31. A manuscript partially supported by a grant to Reed College from the Resources for the Future Inc., Washington, D.C., on file at Dep. of Interior Library, Bonneville Power Administration, Portland, Oregon.

[3]Claire, Errol W., 1977. Fish populations and habitat studies on Camp Creek. Unpublished data on file at Oreg. Dep. Fish and Wildl., John Day.

[4]Duff, Donald A., 1977. Big Creek aquatic habitat management and impacts from livestock grazing. Unpublished paper presented at the Bonneville Chapter of the Am. Fish Soc., Annu. Meet., Ramada Inn, Salt Lake City, Utah. 13 p.

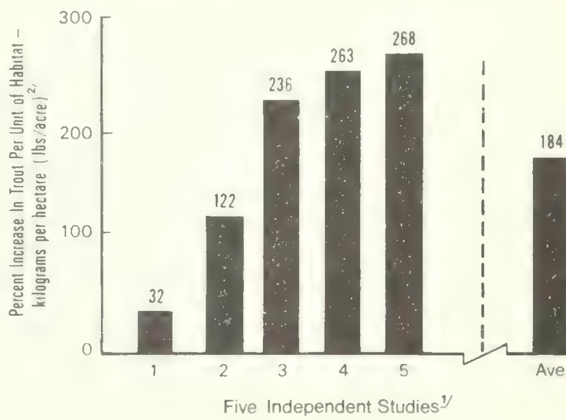


Figure 6.—Percent increase in trout production in areas of controlled or light cattle grazing as compared with heavily grazed areas of the same streams.

[1]Source:
1. Gunderson (1968): Rock Creek, Montana—brown trout (*Salmo trutta*) (exclosure).
2. Claire (1977): Camp Creek, Oregon—rainbow trout (*Salmo gairdneri*) (exclosure with controlled grazing).
3. Marcuson (1970): Rock Creek, Montana—brown trout (exclosure).
4. Duff (1977): Big Creek, Utah—rainbow and cutthroat trout (*Salmo clarki*) (exclosure).
5. Lorz (1974): Little Deschutes River, Oregon—brown trout (light grazing).

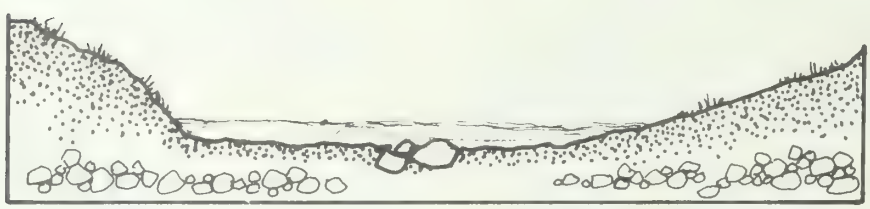
[2]Percent increase of trout in kilograms per hectare (lbs/acre) for all studies except Camp Creek; Claire (1977) reported increase in number of fish per linear distance of stream studies.

could be increased about 200 percent if management decisions were made to optimize habitat conditions for trout.

Water temperatures in areas adjacent to exclosures were found to be high; and as a result, such fishes as suckers, dace (*Rhinichthys* spp.), and shiners (*Richardsonius* spp.) were prevalent. In one stream, for example, dace were 4.5 times more numerous in a stream section with season-long grazing use than within a 13-year-old exclosure with controlled grazing (no grazing within the first 6 years and light grazing thereafter). Wa temperatures from 26 August to 11 Septeml downstream from the exclosure were 6.7 (12°F) higher 25.6°C (78°F) than within the closure 18.9°C (66°F) (Claire 1977).

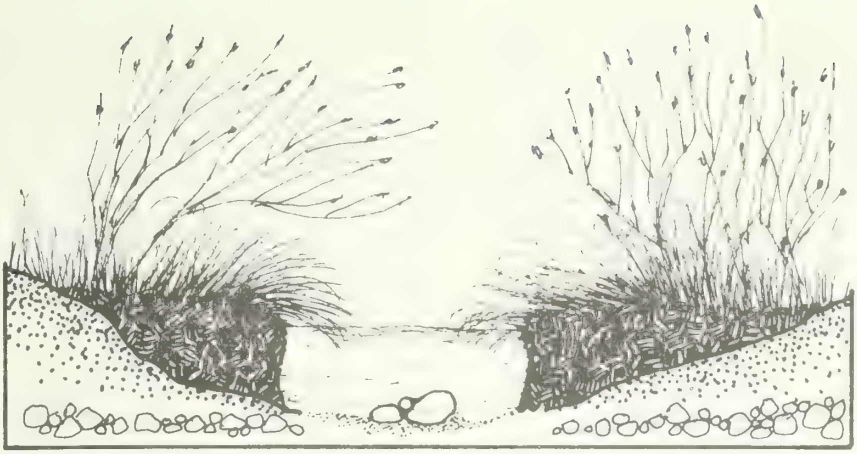
Streambank erosion has also been comm outside exclosures. Heavily grazed sectio generally cause the stream channel to widened, resulting in decreased water dep and increased water temperature (White a Brynildson 1967, Van Velson n.d.) (fig. 7 Figure 7b and 7c illustrate the natural strea

Figure 7.—Stream habitat conditions with heavy grazing (A) and subsequent improvement over a 10-year period—providing livestock grazing is discontinued (B and C). Adapted from White and Brynildson (1967).



A. Late summer stream conditions with heavy livestock use: Bank vegetation and aquatic vegetation grazed and trampled. Banks eroded and streambed mostly covered by shifting sediment. Water and streambed exposed to sun. These conditions offer trout no cover, no place to spawn, little food, unfavorable temperatures, and turbid water.

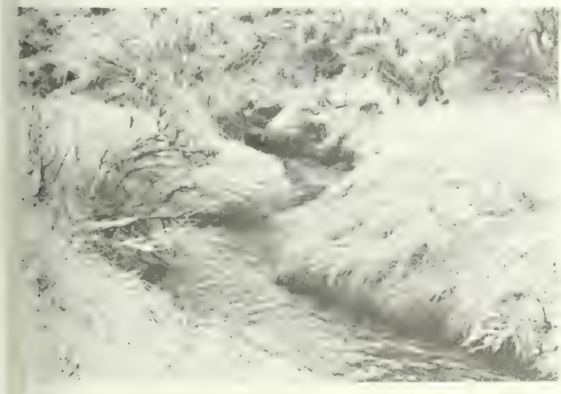
B. Late summer conditions after 2 to 3 years without grazing: Streambank vegetation includes grasses, young willows, wild rose and alder—vegetation binding soils, sediment being deposited, and stream receiving some shade. Trout habitat improved with increased cover, more food, and better spawning conditions.



C. Late summer stream conditions after 5 to 10 years of non-use by livestock: Streambanks are well vegetated with 2.4- to 4.6-m- (8- to 15-foot-) high willow, wild rose, alder, cottonwood, red osier dogwood, grasses, shrubs, and sedges. Stream has numerous overhanging banks with little sediment movement. Excellent trout habitat providing cover, cold water, food, and spawning area.

rocesses that restore degraded habitats to roductive conditions when grazing use is liminated for a number of years (fig. 8).

Although no documentation was found, it eems to be obvious that any wild herbivore us-ng the riparian zone is going to have an effect n the condition, species composition, and rowth of the plant community.



Igure 8.—Natural processes can restore degraded habitat to a productive condition for native trout when livestock grazing is eliminated. (Photograph by Robert R. Kindschy)

Management Tips

Livestock grazing is the dominant land management program on public lands in southeastern Oregon. Most of the tips concern this land use, and are designed to assist a manager in making decisions that are beneficial for trout production.

The previously discussed optimal habitat requirements for trout are repeated here as generalized objectives, the achievement of which will lead to good trout habitat:

1. Where possible, streams should be 75 percent or more shaded with a vegetative canopy cover to maintain summer water temperatures below 21.1°C (70°F).

2. Streambanks should be well vegetated to prevent active erosion from occurring on at least 80 percent of their total lineal distance.

3. Instream cover for trout should be about 50 percent of the total stream area, including overhanging bank vegetation on 50 percent or more of the streambanks.

4. At least 75 percent of riffle-rubble areas of streams should be free of siltation or fine sediments.

Attainment of all of these goals on all streams may not be possible because of various site-specific limitations on particular streams. Specific actions that may be taken to maintain or improve native trout habitat are as follows:

1. Implement grazing systems that will create and/or maintain the requirements for good condition trout habitat. Livestock management alternatives that should be considered to improve degraded stream habitats and riparian zones include: (a) deferred grazing on streamside areas until fall months, and (b) on high priority streams, schedule exclusion of riparian areas from livestock grazing until substantial habitat improvement has occurred—this may require from 5 to 10 years, depending on the existing conditions of the habitat. Permanent elimination of livestock grazing in most areas is neither desirable nor feasible, but grazing should be closely controlled to improve habitats in poor condition and to maintain healthy riparian vegetation and productive fish habitat.

2. Fencing may be necessary on the most important trout streams to protect the easily damaged habitat. The entire riparian zone should be excluded from pastures in these areas. Corridor fences are usually considered undesirable but can be used to obtain immediate improvement in small areas where streambank erosion is a serious problem. Gap fences, less expensive to erect, often require annual maintenance.

3. Encourage livestock use away from riparian zones. Management practices, such as salting, water developments, and herding, can relieve pressure on riparian zones and markedly improve upland range conditions.

4. Artificial revegetation of streambanks may produce vegetative recovery more rapidly than natural revegetation. Recovery of critical streamside cover can be accelerated by several years when trees, shrubs, and grasses are planted. Plantings in the riparian zone should include willow (*Salix* sp.), alder (*Alnus* sp.), cottonwood (*Populus* sp.), quaking aspen (*Populus tremuloides*), black locust (*Robinia pseud-acacia*), chokecherry (*Prunus virginiana*), Russian olive (*Elaeagnus angustifolia*), red-osier dogwood (*Cornus stolonifera*), reed canary grass (*Phalaris arundinacea*) (Rise variety), streambank wheatgrass (*Agropyron dasytachyum*), and yellow-blossom sweet clover (*Melilotus officinalis*). Research is needed, however, to develop varieties of riparian plants that are less palatable to livestock.

5. Stream improvement structures should be installed only after a thorough field evaluation. Recommendations of both hydrologists and fishery biologists should be included in project planning. Recommended structures for streams are trash catchers, gabions, small rock dams, individual boulder placement, rock jetties, and silt-log drops. The type of instream structure recommended will depend on site-specific conditions of each stream. Some structures could serve the dual purpose of increasing the water table in areas of former wet meadows as well as improving trout habitat.

6. Riparian vegetation should be protected during herbicide treatments designed to improve range forage for livestock use. Certain chemicals are toxic to fish and other aquatic organisms. Use of streamside buffer strips and adherence to all other standard procedures for herbicide applications, including close contract supervision, are imperative.

7. Controlled beaver (*Castor canadensis*) populations are an asset to small trout streams and their attendant wildlife (Kirby 1975). They help retain water, influence the water table in the streamside zone, and provide some good pools for trout. A regulated trapping harvest is essential to maintain healthy beaver populations compatible with good trout habitat. Regulation of livestock grazing is also essential to perpetuate viable stands of aspen and willow (DeByle 1976, Schier 1976, Smith et al. 1972).

Uncontrolled beaver populations may be destructive to trout habitat on some higher elevation streams. Beaver can completely cut down large aspen groves and willow patches (Hall 1960). After food supplies are eliminated, the beavers either move or die of starvation.

In southeastern Oregon, for example, riparian aspen groves are small, relatively rare, and are easily eliminated by the combination of beaver and livestock use. Consequently, many aspen groves have little or no regeneration or regrowth because young plants are eaten by livestock before they become well-established. Since aspen regeneration is through adventitious shoots, root suckers, or root sprouts, there are ways to rejuvenate a declining grove that is not subject to either beaver or livestock use (Jones 1975, Jones and Trujillo 1975, Schier 1975, 1976). Where beaver or livestock use an aspen grove, however, exclusion of livestock will be necessary for a long enough period of time to allow the young aspen to become established and large enough to withstand livestock use.

Extensive soil erosion may occur within the former aspen-willow areas, and beaver ponds usually become filled with sediment. Old beaver dams may eventually break and discharge heavy sediment loads downstream.

8. Improvements of existing roads or construction of new roads along streams inhabited by native trout could have severely adverse effects upon these fish populations (Whitney and Bailey 1959). Roads along streams destroy the riparian vegetation and thereby remove trout cover and increase water temperatures. Further, sediment movement into streams from roads, particularly road construction, is detrimental to aquatic life. If streamside road construction is unavoidable, however, culverts should be placed so as to minimize erosion and provide easy fish passage.

Improved, well-developed roads usually result in better access and heavier public use. Wild trout, therefore, are generally less abundant in areas where streams are easily accessible.

9. Recreation use will continue to increase in southeastern Oregon. It is suggested, therefore, that developed recreation facilities should not be constructed on any native trout stream because of the tendency to overfish a stream. New recreational facilities should be located in the more accessible areas where fish populations can be maintained either by stocking hatchery trout or with warm-water species.

In addition, if viable trout populations are to be maintained, the construction of trails along native trout streams is not recommended.

10. Water management of large reservoirs occurring on or adjacent to public lands in southeastern Oregon are under the control of the Bureau of Reclamation and/or irrigation districts. Because of this, available options to manage fish habitat must be related to the surrounding lands and upper watersheds. If the surrounding rangelands are in good condition, erosion will be minimized and water flowing into reservoirs will be of sufficient quality to maintain good fish populations.

Small reservoirs, constructed for stock water developments, sometimes have water conditions suitable for fishery development. If water-gap fences are used to keep livestock out of small reservoirs, they may cause maintenance problems. For example, ice breaks such fences; and where reservoirs fluctuate, livestock often get around the ends of the gap fence. Fencing may be necessary, therefore, to exclude livestock from the entire reservoir area. Water can then be piped to a livestock watering trough outside of the fence.

11. Springs that help maintain water quality and quantity in downstream fish habitats, especially during summer low-flow periods, should be protected. Furthermore, isolated springs in the desert environment of southeastern Oregon sometimes contain unique or rare species of fish.

12. Each spring, the Oregon Department of Fish and Wildlife stocks the larger reservoirs, parts of the Malheur River, and many of the smaller water developments with fingerling rainbow trout. Streams that are easily accessible and support heavy angling pressure may receive legal-sized rainbow trout each year. To help maintain strains of wild trout, hatchery trout should not be released in streams where native trout occur.

Habitats not suited for trout production, but with fishery potential, may be stocked with warm-water game fish if there is no adverse impact on native non-game species.

Land managers should contact the local fisheries biologist if they think some of their water developments are suitable for fish production. If a reservoir is found to be suitable habitat, the Department of Fish and Wildlife will stock the desired species and manage the fishery.

Management practices—on any part of a rangeland watershed—ultimately affect the riparian vegetation, water quality and quantity, and fish habitat. Proper resource management, especially livestock grazing, is imperative if we are to insure the welfare of our aquatic habitats and their riparian zones. Streams, rivers, lakes, and their attendant riparian zones are the barometers that reflect the care man takes of his land-support base. Spence (1938, p. 23) summed it up:

> ...Is it not wiser, under any condition, to suffer now and begin to rebuild on investment than to continue to gamble year after year, and finally end with a total loss...? The problem becomes even more serious when the welfare to future generations is considered.

Fortunately, natural processes not only can help restore streams that are in poor condition but also can help reverse the downward trend of stream habitats. With the existing knowledge of natural processes, management strategies can be tailored to improve stream habitats; but their maintenance and repair will require the cooperative efforts of both public and private rangeland managers because streams ignore political boundaries.

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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

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ABSTRACT

Edge can be a measure of overall diversity of any area. Diversity is considered as inherent (community/community) edge, induced (successional stage/successional stage) edge and total edge. Size of stands are related to expected wildlife diversity.

KEYWORDS: Wildlife habitat, range management.

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This publication is part of the series **Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon**. The purpose of the series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands in order that the manager may make fully informed decisions.

The information in this series is specific to the Great Basin of Southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area but in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive whole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.

Introduction

An edge (fig. 1) is the place where plant communities meet or where structural conditions within plant communities come together. The area influenced by the transition between communities or conditions is called an ecotone (fig. 2). Edges and their ecotones are usually richer in wildlife than are the adjoining plant communities or structural conditions. As a result, they are an important consideration in wildlife management.

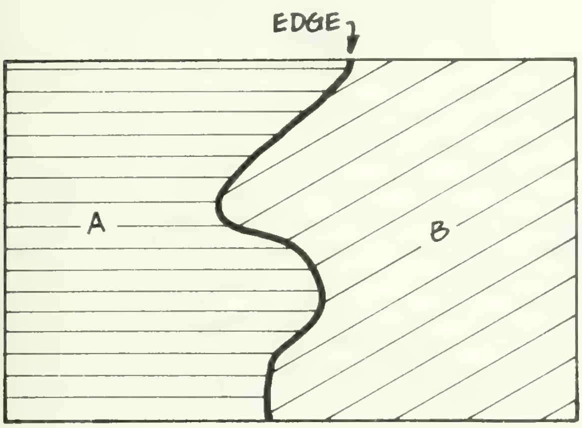
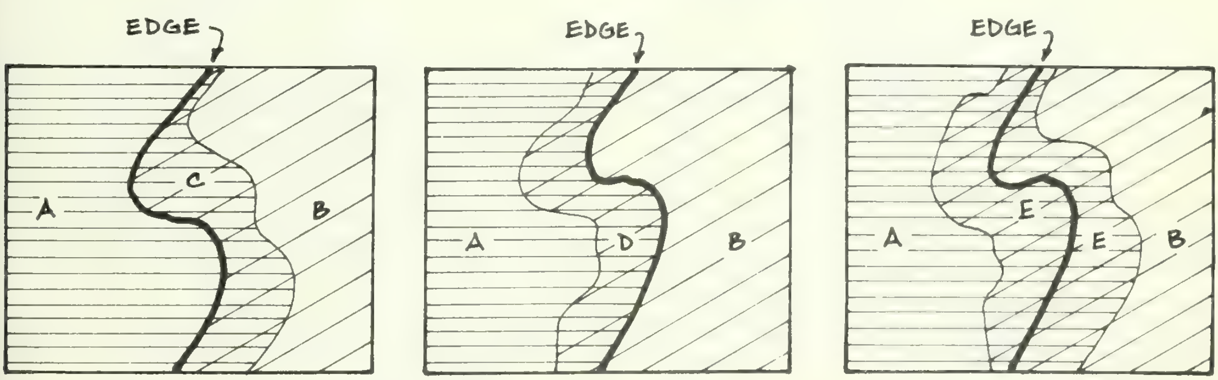


Figure 1.—An edge is the place where plant communities (A and B) or structural conditions within a plant community come together.

Aldo Leopold (1933, p. 132) stated that "game [wildlife] is a phenomenon of edges." Wildlife "occurs where the types of food and cover which it needs comes together, i.e., where these edges meet. . . .We do not understand the reason for all of these edge-effects, but in those cases where we can guess the reason, it usually harks back to the desirability of simultaneous access to more than one environmental type, or the greater richness of border vegetation or both."

As biologists investigated the effects of edge on wildlife, they began to recognize other relationships that helped explain the phenomenon. These concepts have become known as the "laws" of dispersion and interspersion.

Dispersion describes the pattern of distribution of individuals in an animal population. In the mathematical sense, dispersion describes the probability of occurrence of such individuals in particular places (Hanson 1962). The law of dispersion says that the potential density of wildlife species with small home ranges that require two or more types of habitat is roughly proportional to the sum of the peripheries of those types (Leopold 1933, Dice 1931). This means that species which are adapted to particular edges and their ecotones increase in proportion to an increase in edges of the appropriate kind.



Some influence of community A extends into B along the edge forming ecotone C.

Some influence of community B extends into A along the edge forming ecotone D.

When influence of community A extends into B and that of B into A, ecotone E is formed.

Figure 2.—Ecotones are formed along edges and may be created in several ways.

The law of dispersion was developed from studies of small animals with small home ranges. Later research indicates that some larger mammals with wider home ranges also use edges and ecotones disproportionately more than other habitats. This is particularly true where the edge occurs between relatively open areas and cover areas (Harper 1969, Reynolds 1962 and 1966).

Interspersion is the intermixing of plant species and plant communities that provides habitat for animals within a defined area (Hanson 1962). The law of interspersion says that the number of resident species requiring two or more types of habitat depends on the degree of interspersion of numerous blocks of such types (Kelker 1964).

The laws of dispersion and interspersion work together to show the range manager how to increase wildlife populations associated with edge. More edge of a particular type will produce more individuals of the wildlife species associated with that edge. Edge effect can be magnified by increasing the interspersion of the types of habitat creating those edges. Wildlife managers, then, have two factors to consider in evaluating the role of edge—the amount of edge and how it is arranged.

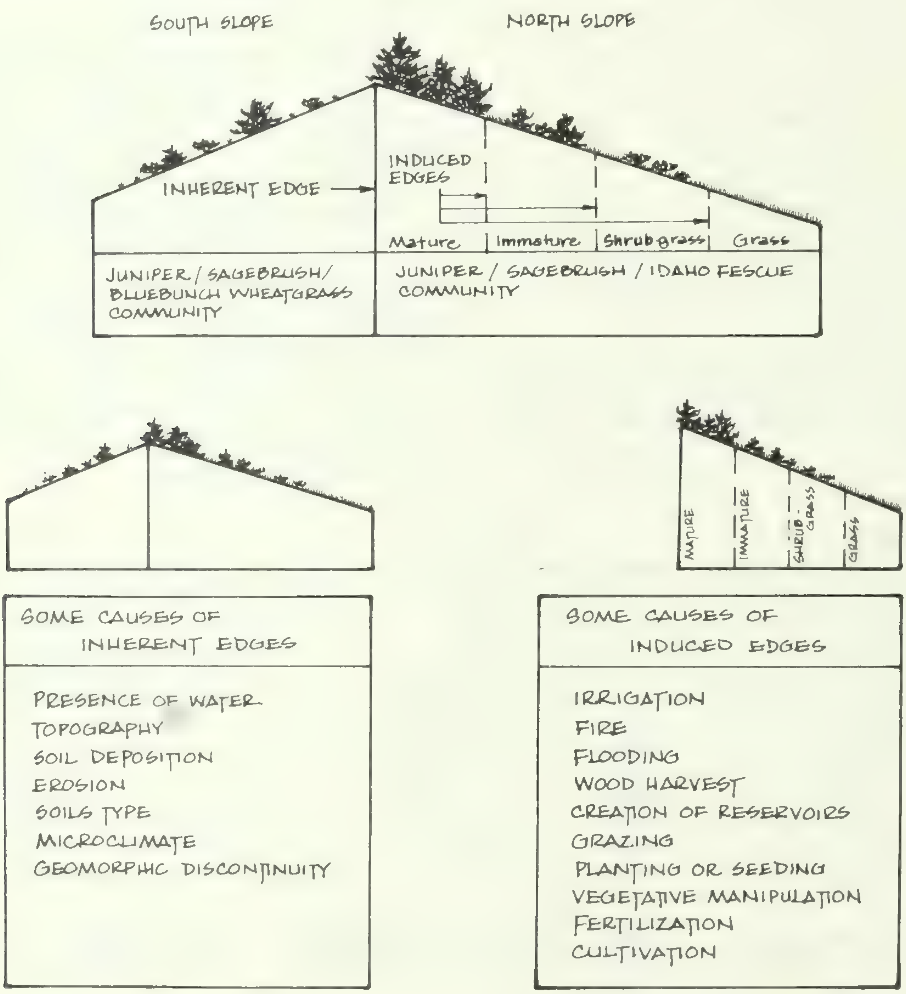


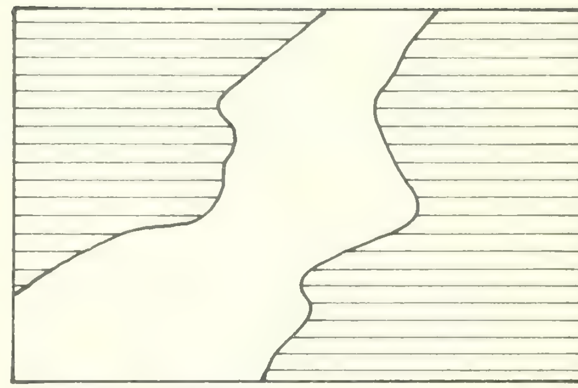
Figure 3.—Inherent edges are created where plant communities meet. Induced edges are created where structural conditions within communities come together. Inherent and induced edges are created by many factors.

Inherent Edge

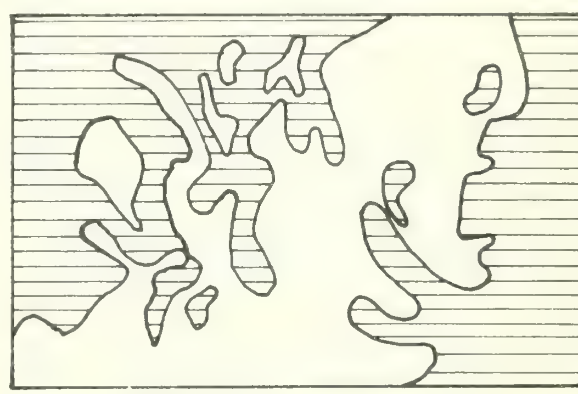
An edge that results from the meeting of two plant communities is called an inherent edge (fig. 3). The plant community is the tangible expression or integrator of the myriad influences acting on a particular site (Daubenmire 1976). The edges between plant communities, as far as the land manager is concerned, are issued with the area—that is, they are inherent. Four of the most obvious natural factors that work separately and in combination to produce inherent edges are: (1) abrupt changes in soil type, (2) topographic differences, (3) geomorphic differences, and (4) changes in microclimate.

Inherent edges are long-term features of the landscape; they result from geomorphic conditions or other factors that create the plant communities involved. For all practical purposes, inherent edges are relatively stable and permanent features of the landscape. They can, however, change. For example, subtle modifications in microclimate and soils over many decades may result in a shifting of the plant communities along the edge until it becomes less abrupt. Sometimes the plant communities are broken into patterns of islands and peninsulas until a mosaic pattern emerges (fig. 4). In other situations, a broadened ecotone may result. An inherent edge can also be created suddenly, for example, by severe sheet erosion.

The conditions of the plant communities that form an inherent edge may be altered by management activities or other short-term phenomena. But since the underlying causes for that edge are related to geomorphic factors, inherent edges are very stable and tend, over time, to return to their earlier vegetative state.



ABRUPT EDGE



MOSAIC EDGE

Figure 4.—Inherent edges may be abrupt or mosaic. Inherent edges sometimes evolve into mosaic edges over prolonged periods.

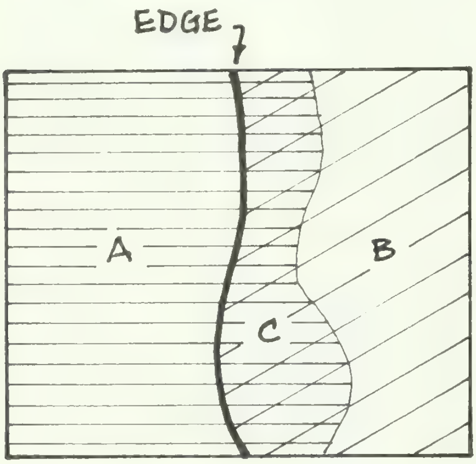
Induced Edges

An edge that results from the meeting of structural conditions within a plant community is called an induced edge (fig. 3). Such edges can be created by management practices or short-term natural phenomenon—that is, they can be induced.

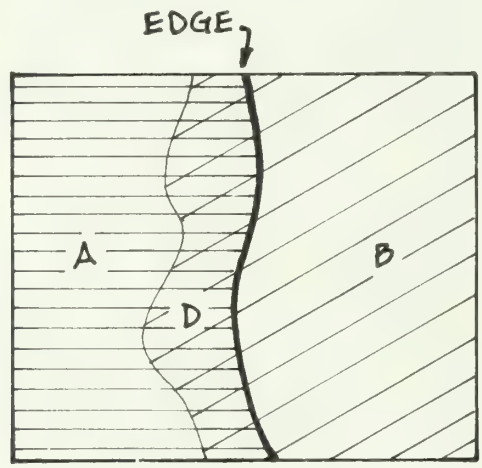
Under natural conditions, induced edges are created by drastic short-term environmental factors, such as fire, disease, insect outbreaks, floods, logging, and erosion (fig. 3). These factors tend to shift plant communities toward earlier, less mature, structural conditions. Compared with inherent edges, induced edges are relatively short lived. Although they may last for many years, they are constantly changing through such things as plant succession and are not permanent features of the landscape.

Importance to Wildlife Management

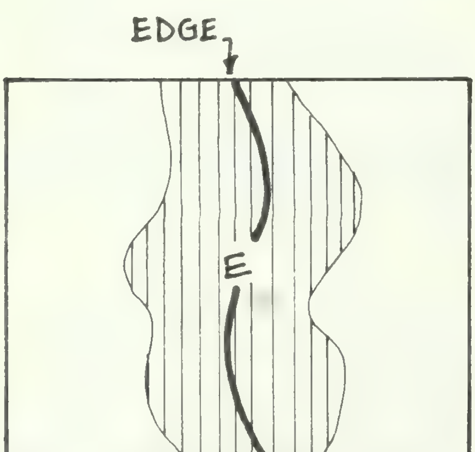
The biological importance of edges to ildlife managers is expressed by the term richness.'' Edges and their ecotones are rich 1 wildlife, both in number of species and of inividuals, because of the additive effect on the flora and fauna when two plant communities or structural conditions come together. In the ecotone there is a mingling of the species common to each type and the addition of other species that may be products of the ecotone itself (Southwood 1972) (fig. 5). In another sense, wildlife richness is related to the plant and habitat diversity expressed in the ecotone.



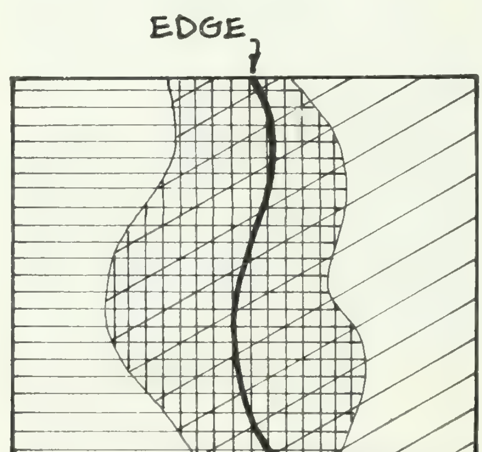
Some wildlife from plant community A overlaps into B within ecotone C.



Some wildlife from plant community B overlaps into A within ecotone D.



Some wildlife is particularly adapted to ecotone E.



The total wildlife use in the ecotone indicates the habitat and species richness associated with edges.

Figure 5.—Species richness associated with edges is an additive effect.

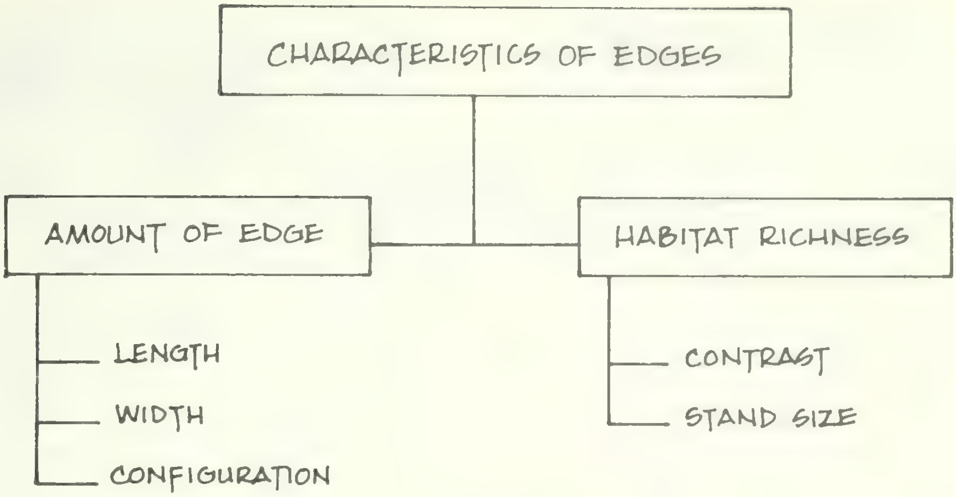


Figure 6.—Edges have characteristics that influence habitat and species richness.

Characteristics of Edges

Edges have characteristics (fig. 6) that influence the amount of edge habitat and the degree of habitat richness. In combination, these two factors determine the total impact of edges as wildlife habitat.

The amount of edge habitat or ecotone in an area is a function of edge width, the length of the edge, and its configuration. The width and length measurements can be used to determine the area of ecotone. An abrupt narrow edge yields less ecotone habitat than a wider edge. Configuration is the arrangement of edges in a pattern that may range from simple to mosaic (fig. 4).

The degree of habitat richness associated with a particular edge is influenced by the size of the plant community and the type of habitat coming together in the edge (Halligan 1974, Johnsgard and Rickard 1957, Wiens 1973). The size of the habitat block has a direct effect on the number of wildlife species in that area (Galli et al. 1976). The species associated with each habitat have a tendency to lap over the edge into the other habitat. So, the larger the habitat blocks, the more species will be associated with them—and the richer the species diversity along the edge.

In addition, habitat richness is associated with the degree of contrast in vegetative structure along the edge. The greater the contrast, the more likely the adjoining habitats are to be very different in structure and in the wildlife species they support. This tends to increase the species richness of the ecotone.

As an example of the effect of contrast, consider the idealized structural conditions in figure 7. There are 5 structural conditions that can be formed into 10 combinations by the joining of 2 conditions. Each combination produces a different degree of contrast. Little contrast is produced by combining closely related conditions. Contrast can be dramatic, however, if an early structural condition is joined with a late condition. The degree of contrast may be determined by subtracting the smaller identifying numbers from the latter. The greater the difference, the greater the contrast.

Area Size and Diversity

At some point, increasing diversity tends toward homogeneity and tends to become decreasingly diverse. Galli et al. (1976, p. 356) said that "The number of species present in a particular habitat is strongly influenced by the size of that habitat." The number of species of

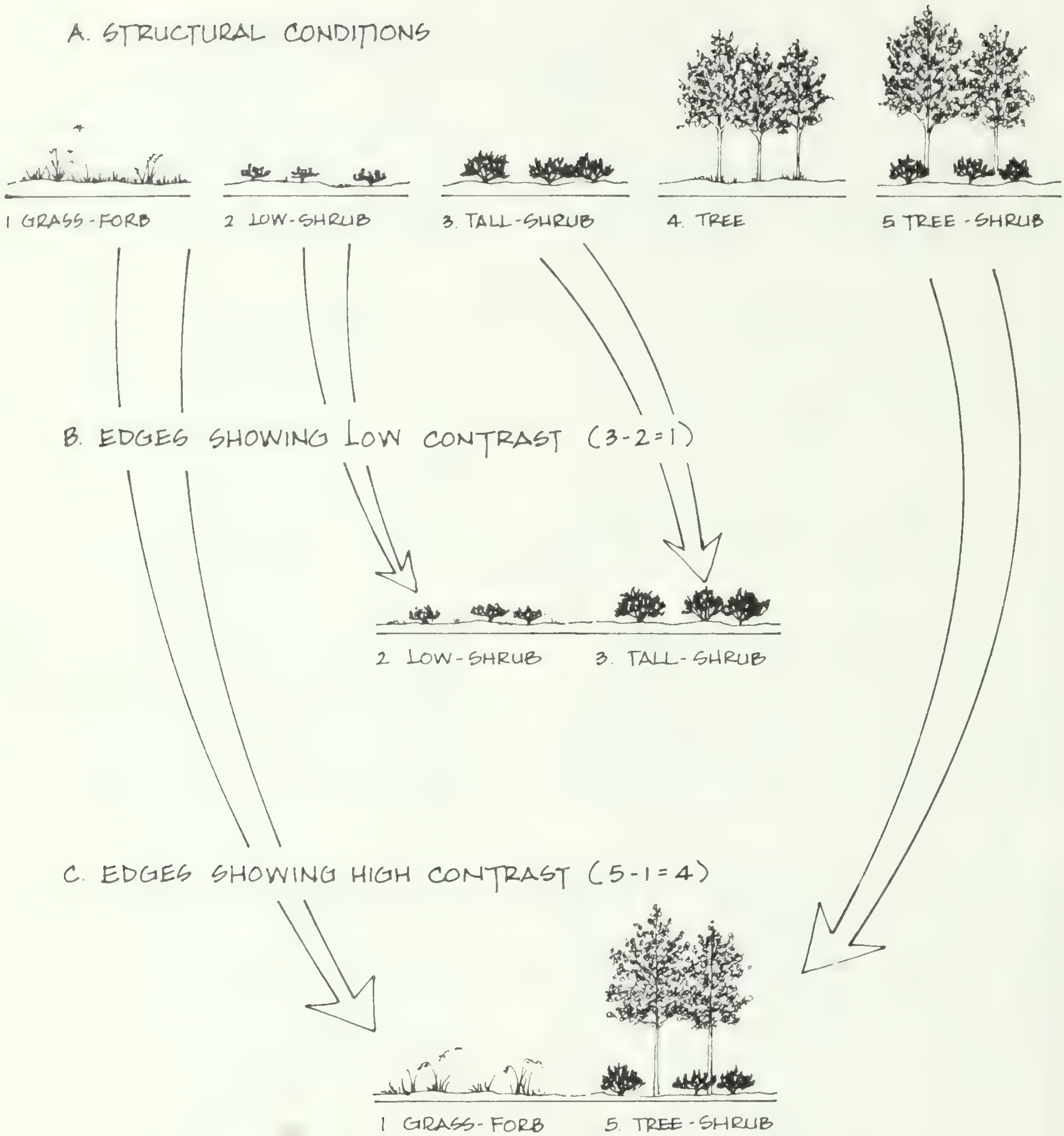


Figure 7.—Different combinations of edges yield different degrees of contrast in structure.

both animals and plants in an area is another indicator of diversity. Arrenhius (1921) and Gleason (1922) seem to have pioneered this concept. The rather voluminous literature on the subject that has developed since that time is well summarized and reviewed by Cain and Castro (1959) and Greig-Smith (1964).

Hopkins (1955), Preston (1960), and MacArthur and Wilson (1967) discuss "species-area curves" or the relationship of numbers of plant and animal species to increasing size of an area in a particular ecological condition. After review of this literature and experimental examination of the relationship

of habitat size to species diversity of birds, Galli et al. (1976) concluded that there was usually a direct linear relationship between the number of species and the logarithm of the area, and that there were distinct relationships for different areas. This simply means that the number of species occupying an area usually increases with the size of the area.

Increasing wildlife diversity tends to become decreasingly diverse when the average size of the habitat blocks becomes smaller than that required to maximize the number of species present (fig. 8). Since no data could be found for rangeland ecosystems, the information of Galli et al. (1976) is used to illustrate the point. Galli et al. studied the relationship between the number of bird species present and the size of blocks of forest habitat interspersed with agricultural lands in New Jersey. They found (p. 363) that "Bird species richness increases significantly through an island size of 24 hectares (59.30 acres) and is likely to continue increasing significantly at forest sizes beyond 24 hectares." Increase in bird species with size of habitat was attributed to: (1) the addition of new species as their minimum habitat size requirements were met, (2) the inclusion of specific habitat components in sufficient quantity, and (3) the presence of specialized conditions in the interior of the forest stands.

Study of a 44-hectare (108.72-acre) plot showed a decline of species numbers over the numbers predicted by the "best-prediction" equation:

$$y = 0.81 + 4.54\, x^{0.05}$$

where y is species richness and x is forest area in hectares. The correlation coefficient (R) was 0.92, accounting for 85 percent of the variation in species richness (R^2). Furthermore, the number of species was less than that encountered on the next largest plot of 24 hectares (59.30 acres). The decline was attributed to a loss of species adapted to edges.

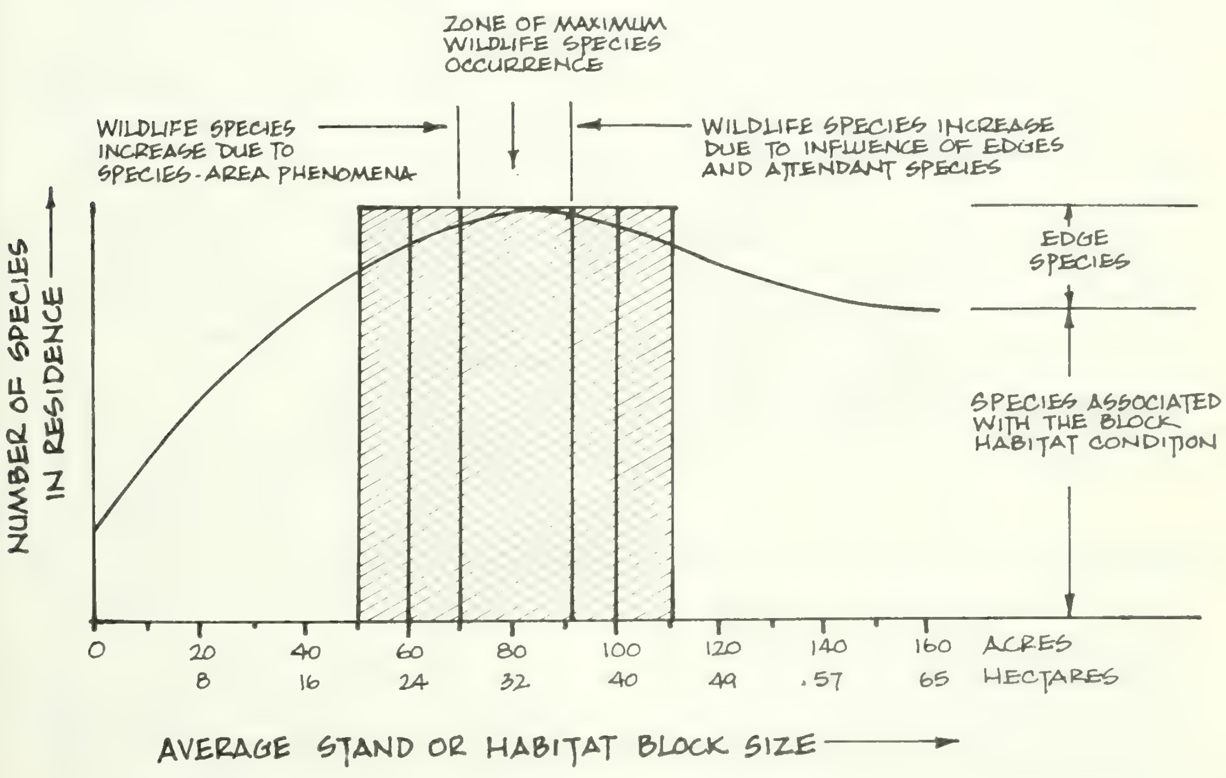


Figure 8.—Wildlife diversity is related to the average size of habitat blocks. The curve is generalized.

Data are lacking for these relationships in southeastern Oregon,but a best estimate is required. Due to the comparative lack of vertical habitat stratification in rangelands as compared to forests, it is obvious that rangeland habitats are not as diverse, and in turn not as rich, as the forest habitats explored by Galli et al. (1976). It seems likely that the increase in habitat size and species occurrence will peak at a higher figure than in forest habitats. Until research data is available, it is suggested that managers assume that wildlife species richness (at least that for birds) will increase significantly with habitat size to about 81 hectares (200 acres) and that bird species richness is a reasonable indicator of the relationship of all vertebrate wildlife to habitat size.

So, wildlife species richness should be approaching the maximum where the average habitat size is approximately 81 hectares (200 acres). Pay special attention to the emphasis on "average." This indicates the existence of habitats both larger and smaller than 81 hectares (200 acres). The larger habitats will accommodate those relatively few species that require habitat blocks larger than the average while smaller habitats will increase edge effect.

Some species may require extremely large areas of contiguous and similar habitats. These would suffer if smaller areas were substituted. The requirement of some species for habitat blocks of specific size should not be confused with the animal's need for solitude or protection from the intrusions of man. In some cases, regulation of man's activities may suffice in lieu of preservation of large areas of pristine habitat. This must be determined on a species-by-species basis.

Edge as a Measure of Diversity

Emphasis on management for diversity in rangeland ecosystems will help to insure the continued existence of the living components of that system—plants as well as animals. That goal is laudable for esthetic or moral reasons alone, but it is also a practical management objective. In the ecological sense, diversity is thought to be related to stability or the ability of a system, when changed from a steady state, to develop forces that tend to restore its original condition (Margalef 1969). Diversity acts as insurance for the system by increasing its ability to withstand disaster.

It has been said that the first rule of intelligent tinkering is to save all the pieces (Leopold 1949). A concern for diversity is a step toward insuring the continued existence of all the pieces in managed rangeland ecosystems.

Some land management agencies are beginning to be concerned about diversity. For example, the United States Department of the Interior, Bureau of Land Management Manual 1603—Supplemental Guidance (1973, p. 12D), under "Long-Term Objectives," directs that BLM will:

> a. Maintain a maximum diversity of wildlife species in sufficient numbers to meet public demands. This will be accomplished by means of habitat management.

And under "Major Principles and Standards" (1973, p. 12D), Manual 1603 further states that:

> c. The essential requirements of wildlife—food, cover, and water—will be maintained so as to provide optimum 'edge effect' and interspersion of habitat components in important wildlife areas.

The Chief of the USDA Forest Service has stated that the wildlife goal for the National Forest System is to insure wildlife diversity and to maintain or enhance wildlife populations (USDA Forest Service 1976). If diversity is a goal in rangeland management, it behooves managers and planners to be able to measure it and account for it in their activities.

Both inherent and induced edges are a direct reflection of the total diversity (fig. 9) in an area. Patton (1975) indicated that edge can be used as a measure of diversity. Traditional diversity indexes (Pielou 1975) require information about numbers of plant and animal

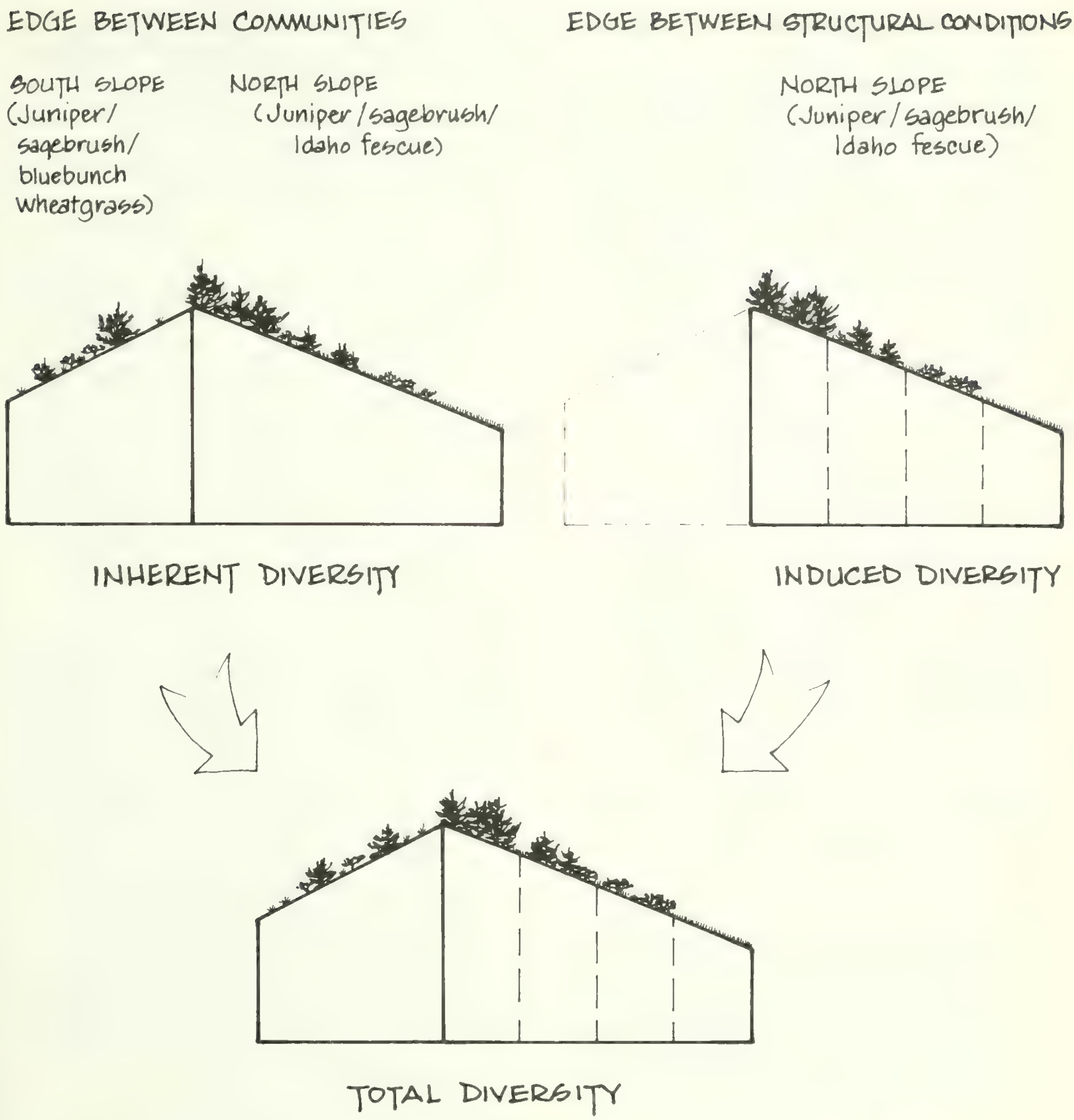


Figure 9.—The type, amount, and arrangement of edges is an expression of habitat diversity.

species and their frequency of occurrence. This approach is too expensive for planners and managers who must operate under severe constraints of budgets, personnel, and time. A feasible alternative is to use edge as an indicator or index of diversity.

There are at least three uses for a diversity index in rangeland management: (1) to investigate trends in habitat diversity, (2) to evaluate management alternatives for their immediate and long-term effects on diversity, and (3) to evaluate the effect of livestock grazing on diversity.

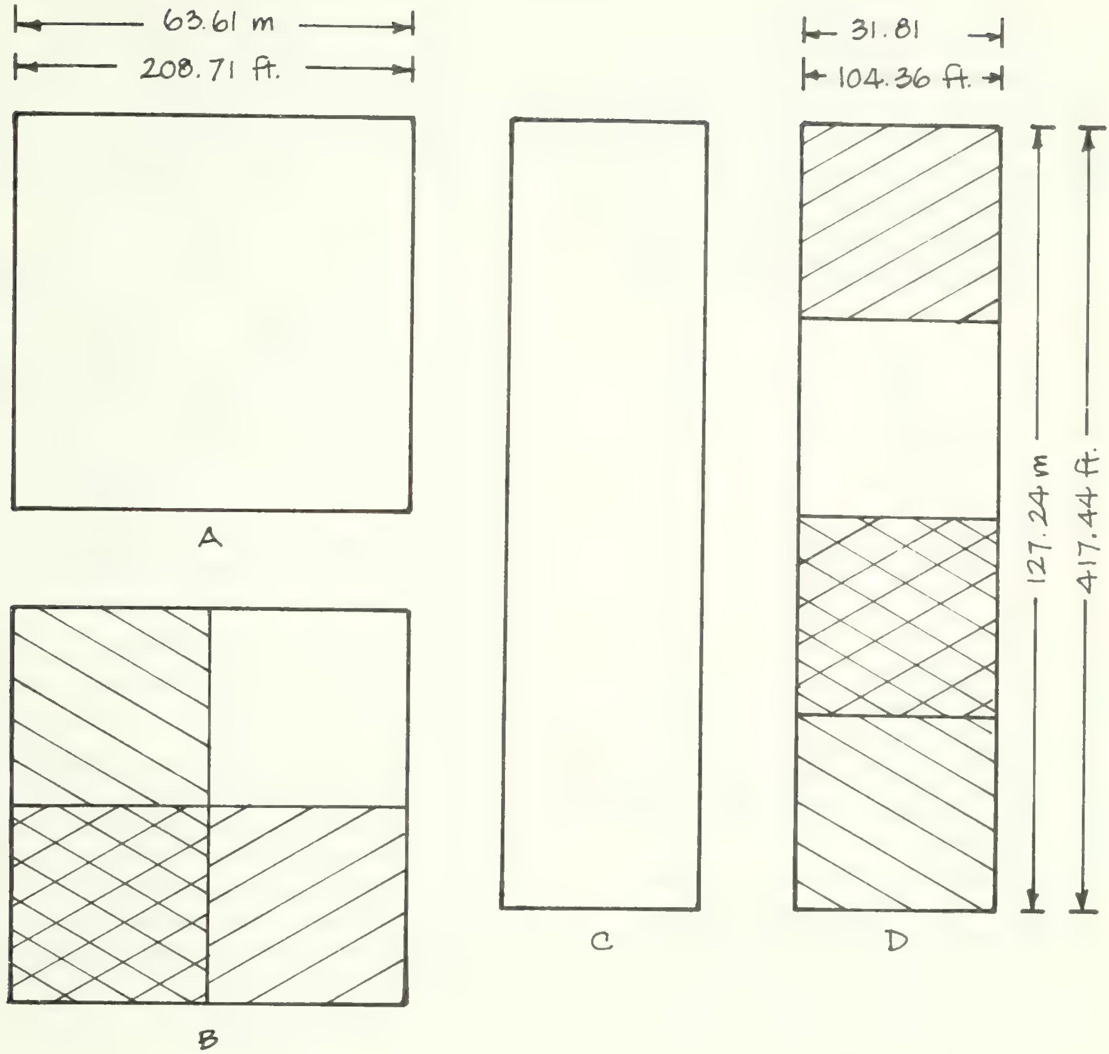
Derivation of Diversity Index

Patton (1975) described a system that expressed, by index, the amount of edge within an area of any given size. Because of the relationship between edge and interspersion and because these factors are a measure of diversity, he referred to this measure as the diversity index. Patton worked entirely with English measurements, but the same results may be achieved with metric measurements.

The following is taken directly from Patton (1975, p. 172). DI signifies the diversity index:

> The geometric figure with the greatest area and least perimeter or edge is a circle. If the ratio of circumference to area of a circle is given an index value of 1, a formula can be derived to compute a comparable index for any area to compare with a circle. Any index larger than 1 is a measure of irregularity and can be used as a DI. A 1-acre circle has a circumference of 739.86 feet and an area of 43,560 square feet. The formula to set the ratio equal to 1 is:
>
> $$\frac{C}{2\sqrt{A \cdot \pi}} = 1$$
>
> where C is the circumference, A is the area, and π is 3.1416. This same formula is often used by limnologists to express shoreline irregularity of a lake. The next step is to restate the formula for habitat diversity as:
>
> $$DI = \frac{TP}{2\sqrt{A \cdot \pi}}$$
>
> where TP is the total perimeter around the area plus any linear edge within the area.
>
> Several examples will show how the DI is computed and what it means. A 1-acre square has 208.71 feet on a side . . .[fig. 10A], and the perimeter of the block is 834.84 linear feet. Substituting these values in the formula:
>
> $$DI = \frac{834.84}{2\sqrt{43{,}560 \times 3.1416}} = 1.13$$
>
> This indicates that a square of 1 acre has 0.13 times more edge than a circle of 1 acre. Dividing the 1-acre block into 4 units of different vegetation types increases the DI to 1.69. . .[fig. 10B]. If the 1-acre block is divided into 4 blocks in a long narrow unit. . .[fig. 10D], then the DI is increased to 1.83. In. . .[fig. 10D] the TP (1,356.68 feet) is computed by adding the outside perimeter (1,043.60 feet) to the 3 inside edges (313.08 feet).
>
> The DI can be expressed as a percentage figure when convenient. It is only necessary to rewrite the formulas as:
>
> $$\text{Percent} = (DI - 1)100$$
>
> For the 1-acre square with a DI of 1.3 the percent is:
>
> $$(1.13 - 1) \times 100 = 13\%$$
>
> This percent figure simply means that the 1-acre square has 13 percent more perimeter than a 1-acre circle. A square-mile block also will have 13 percent more perimeter than a circle of the same area.

Patton's diversity index assumes that the total perimeter of an area is actually edge. In that case, the index is valid. But usually all or part of the perimeter of an area under consideration is not an edge in the ecological sense. In such cases, the index will not be valid. Furthermore, if diversity is expressed as a product of edge, it seems best to consider it as derived from two sources: (1) inherent edge, and (2) induced edge (see fig. 9). As a result, Patton's index has been modified in the following discussion to make it more applicable in land-use planning and land management.



CONFIGURATIONS OF 1-ACRE AREA	TOTAL EDGE		DIVERSITY INDEX
	METERS	FEET	
A	254.46 m	834.84 ft	1.13
B	381.69 m	1,252.26 ft	1.69
C	318.09 m	1,043.60 ft	1.41
D	413.52 m	1,356.68 ft	1.83

Figure 10.—Comparison of diversity indexes for four 1-acre configurations. Feet converted to meters by multiplying by factor 0.3048 (adapted from Patton 1975).

Inherent edges are site-related and are created when plant communities meet. Such edges may be considered as the degree of diversity "given" to the area. Induced edges occur when structural conditions within plant communities come together. Induced edges can be produced when and where desired by the rangeland manager and are certain to result from any activity that alters vegetative structure.

Inherent Diversity Index

The inherent diversity index is computed as follows:

$$\text{Inherent DI} = \frac{TE_c}{2\sqrt{A\cdot\pi}};$$

where TE_c is the total edge between plant communities in feet or meters found within or on the perimeter of the area under consideration, A is the area expressed in square feet or square meters, and π is 3.1416. The inherent DI is expressed as a percentage increase over perfect simplicity by this process:

Inherent DI, percent = (Inherent DI)100

Perfect simplicity may be expressed as DI = 0. Perfect simplicity may also be viewed as any delineated area which has no edge present—either internally or on the periphery.

In figure 11, a 60.9- × 60.9-meter square of 3 708.8 m^2 (200- × 200-foot square of 40,000 ft^2) is divided into four equal plant communities. In this case, the perimeter of the area is also inherent edge. The inherent DI in percent is computed as follows:

$$\underset{\text{(in feet)}}{\text{Inherent DI}} = \frac{TE_c}{2\sqrt{A\cdot\pi}} =$$

$$\frac{1{,}200\ \text{ft}}{2\sqrt{(40{,}000\ \text{ft}^2)(3.1416)}} = 1.69.$$

$$\underset{\text{(in meters)}}{\text{Inherent DI}} = \frac{TE_c}{2\sqrt{A\cdot\pi}} =$$

$$\frac{365.8\ \text{m}}{2\sqrt{(3\ 708\ \text{m}^2)(3.1416)}} = 1.69.$$

Inherent DI in percent = (inherent DI)100 = (1.69)100 = 169%.

The number of plant communities represented is also an important component of inherent diversity. Although the number of plant communities will obviously increase the inherent DI in percent, an added descriptor showing the number of communities seems appropriate (Patton 1975). The descriptor may be added in parentheses after the inherent DI in percent. In this case:

Inherent DI in percent (number of communities) 169%(4).

In this example the total perimeter represents inherent edge and was included in calculating TE_c. If all or part of the perimeter had not been inherent edge, those parts would not have been used in computing TE_c. In other words, only the portions of the perimeter that are inherent edge are used in deriving TE_c. This is a modification of the approach described earlier (Patton 1975).

Induced Diversity Index

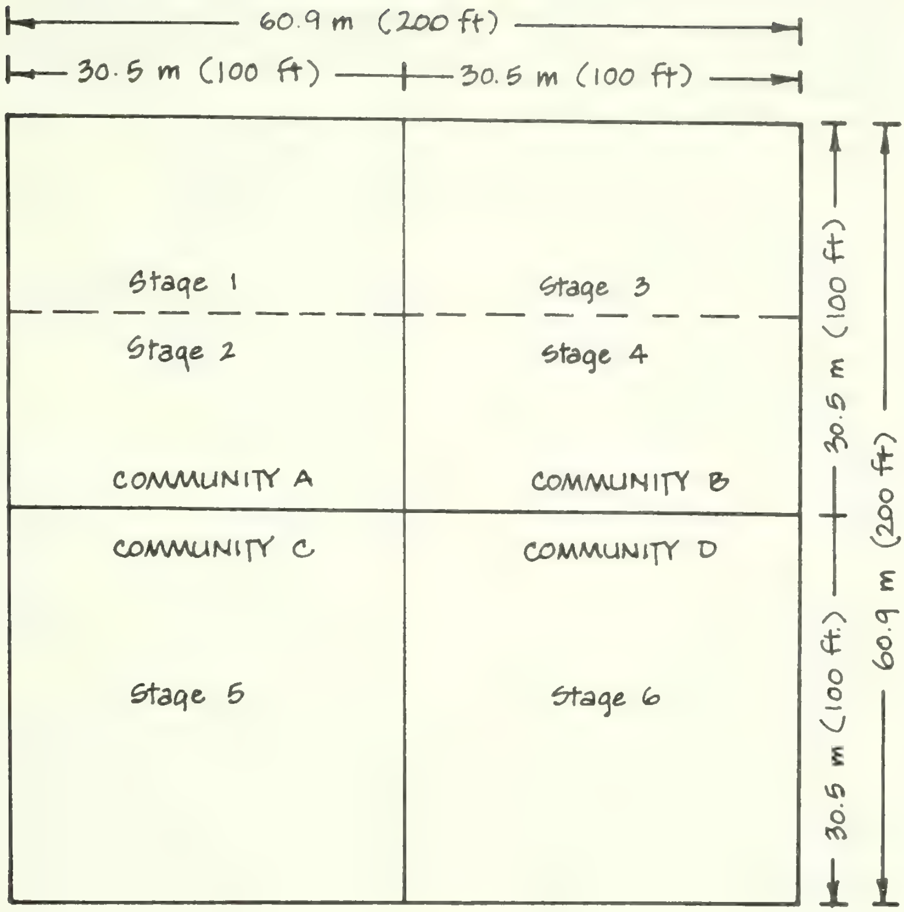
Induced diversity can be expressed in the same manner:

$$\text{Induced DI} = \frac{TE_s}{2\sqrt{A\cdot\pi}}$$

where TE_s is the total length of the edges (in feet or meters) created between structural conditions, within plant communities or along their peripheries, for the area under consideration.

Then,

Induced DI in percent = induced DI(100).



PLANT COMMUNITIES: A, B, C, D
STRUCTURAL CONDITIONS: 1, 2, 3, 4, 5, 6
INHERENT EDGES: ————————
INDUCED EDGES: — — — — — — —
TOTAL AREA IN METERS: (60.9 m) (60.9 m) = $3\ 708.8\ m^2$
TOTAL AREA IN FEET: (200 ft) (200 ft) = 40,000 ft

TOTAL INHERENT EDGE:	365.8 m	1,200 ft
TOTAL INDUCED EDGE:	+60.9 m	+ 200 ft
TOTAL EDGE:	426.7 m	1,400 ft

Figure 11.—An area showing plant communities, structural conditions, and edges.

Again consider figure 11. The dotted lines represent induced edge within plant communities A and B. The TE_s is 60.9 meters (200 feet) and the total area is 3 708.8 square meters (40,000 ft^2). The induced DI in percent is computed as follows:

$$\text{Induced DI (in feet)} = \frac{TE_s}{2\sqrt{A^{\cdot}\pi}} =$$

$$\frac{200 \text{ ft}}{2\sqrt{(40{,}000 \text{ ft}^2)(3.1416)}} = 0.28.$$

$$\text{Induced DI (in meters)} = \frac{TE_s}{2\sqrt{A^{\cdot}\pi}} =$$

$$\frac{60.9 \text{ m}}{2\sqrt{(3708.8 \text{ m}^2)(3.1416)}} = 0.28.$$

Induced DI in percent = induced DI(100) = 0.28(100) = 28%.

The number of structural conditions represented should be added in parentheses after the induced DI in percent as a further descriptor of induced diversity:

Induced DI in percent (number of structural conditions) 28%(6)

Total Diversity Index

Total DI is an index of the combined effects of inherent DI and induced DI. This is computed as follows:

$$\text{Total DI} = \frac{TE_{c+s}}{2\sqrt{A^{\cdot}\pi}}$$

and,

Total DI in percent = (Total DI)100;

where TE_{c+s} is the total length, in meters or feet, of all inherent and induced edges. This is computed as follows (see fig. 11):

$$\text{Total DI (in feet)} = \frac{TE_{c+s}}{2\sqrt{A^{\cdot}\pi}} =$$

$$\frac{1{,}400 \text{ ft}}{2\sqrt{(40{,}000 \text{ ft}^2)(3.1416)}} = 1.97.$$

$$\text{Total DI (in meters)} = \frac{TE_{c+s}}{2\sqrt{A^{\cdot}\pi}} =$$

$$\frac{426.7 \text{ m}}{2\sqrt{(3708.8 \text{ m}^2)(3.1416)}} = 1.97.$$

Total DI in percent = total DI(100) = 1.97(100) = 197%.

Total DI in percent can be enhanced by showing the contributions of the number of plant communities and the number of structural conditions as follows:

Total DI in percent (number of communities) (number of structural conditions) = 197%(4)(6).

Note that when the expressions of inherent and induced diversity are added they equal total diversity:

	Inherent DI in percent	169
+	Induced DI in percent	+ 28
	Total DI in percent	197

Therefore, if any two of the indexes are known, the third may be derived by appropriate addition or subtraction.

Mapping Codes

The indexes just discussed can be helpful in evaluating the general status of edges and diversity in a planning area. The rangeland

manager may find it desirable to account for the amount and characteristics of individual edges in an area. The following coding system is suggested:

Edge type:	T = induced; P = inherent
Community:	Community-community for inherent edges; Community for induced edges. The code is the first two letters of the genus and species names.
Length:	In feet or meters
Average width of the ecotone:	In feet or meters
Contrast:	1 to 4
Configuration:	A = abrupt; M = mosaic

Example: T - *AR TR* - 1,700 - 25 - 4 - A

The codes in this example mean that the area has an edge that is inherent; it is within the *Artemisia tridentata* community; it is 1,700 feet long and 25 feet wide; the contrast is 4; and it has an abrupt edge (A).

Management Tips

Each range area has a unique set of possibilities for diversity. One area may have a high degree of diversity as a result of its inherent mixture of communities. Conversely, an area may have only one or a few communities all in the same structural condition and may be a good candidate for improvement in diversity if that is in keeping with management objectives.

The diversity of an area cannot be increased indefinitely by making more and smaller "islands" and more edges. Beyond some point, the area's increasing heterogeneity tends toward homogeneity (fig. 9). The pieces become so small and mixed that they assume a sameness.

Diversity as a concept and goal of wildlife habitat management has become a shibboleth for many land-use planners and range managers. This is because diversity seems to be a worthy goal. First, a wide variety of habitats are maintained which assures the presence of many kinds of wildlife. Second, all pieces of the system are preserved. Third, the system is protected to some extent from potential disasters.

As a result, the use of diversity as a goal has a certain biopolitical appeal. Very broad diversity goals, loosely stated, can be used to justify management activities and make accountability unlikely. In this context, diversity goals are essentially nonconstraining. The range manager can give a good story about wildlife habitat management, never state the objectives precisely, and never have to show exactly how the goal of diversity was accomplished. This is a misuse of the concept.

Diversity as a goal in management must be used with caution. The degree of habitat diversity can be "good" or "bad" only in relation to management goals and objectives. And maximum diversity may not always be an appropriate choice. For example, it is impossible to maximize diversity and at the same time maximize numbers of a particular species. Thus, diversity is a measure of habitat condition and must be considered in combination with the needs of the affected species. A mix of management for species richness and featured species management is feasible and will probably preclude the loss of any species while insuring desired yields of the featured species—usually game or threatened or endangered species (Gill et al. 1976).

Diversity is meaningful only in the context of clearly stated range management objectives. If diversity is a goal of land management, it can be accomplished only if the manager is willing and able to measure changes in diversity. Without a concise statement of goals and adequate measurement of the status of diversity, range managers cannot be held accountable.

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WILDLIFE HABITATS IN MANAGED RANGELANDS — THE GREAT BASIN OF SOUTHEASTERN OREGON

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WILDLIFE HABITATS IN MANAGED RANGELANDS-- THE GREAT BASIN OF SOUTHEASTERN OREGON

MANMADE HABITATS

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FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

ABSTRACT

Manmade structures on rangelands provide specialized habitats for some species. These habitats and how they function as specialized habitat features are examined in this publication. The relationships of the wildlife of the Great Basin to such structures are detailed.

KEYWORDS: Wildlife habitat, range management.

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This publication is part of the series **Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon**. The purpose of the series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands in order that the manager may make fully informed decisions.

The information in this series is specific to the Great Basin of Southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area but in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive whole. Although each part will be an independent treatment of a specific subject, when combined in sequence, the individual parts will be as chapters in a book.

Individual parts will be printed as they become available. In this way the information will be more quickly available to potential users. This means, however, that the sequence of printing will not be in the same order as the final organization of the separates into a comprehensive whole.

A list of the publications in the series, their current availability, and their final organization is shown on the inside back cover of this publication.

Wildlife Habitats in Managed Rangelands — The Great Basin of Southeastern Oregon is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and United States Department of the Interior, Bureau of Land Management.

Introduction

Manmade structures, such as buildings, roads, bridges, rock walls, and wooden corrals and fences have long been a part of western rangelands. Although they were not built with an idea of blending into their surroundings, after being weathered and molded by the environment, these manmade intrusions become part of the landscape. Few men living can remember when they were not there. Such structures, when obviously "old" or of a past era, come to be considered as part of our national heritage and are preserved for the consideration and enjoyment of the public.

The rustic individualism reflected by these structures is captured by artists with brush and camera. But little does an artist know of the role the environment has played in molding their character. True, the builder has left behind the design of his labor, and weather and age have blended both labor and design into its surroundings. But, the sun and wind and rain and snow are not alone in contributing to making an abandoned homestead a thing of rustic attractiveness. The generations of plants and animals that live along each stretch of road and fence, under each bridge, and in and around each abandoned homestead add the final touches of individualism.

Although man has seldom viewed his intrusions into the environment as habitats for wildlife, their value as wildlife habitat is slowly being perceived. For example, Lustig (1976:4), in his article "Living Fences. . .An Alternative," put it this way:

> Robert Frost's poem 'Mending Fences' popularized the old proverb 'good fences make good neighbors.' However, for today's ecologically aware populus [sic], a more appropriate statement might be 'good fences bring good neighbors.' And so they do; both in urban and rural areas. . . . Any concerned land owner can easily change an ecologically sterile boundary line or fence row into a 'mini' wildlife sanctuary and thereby maximize the species diversity that he and his family can enjoy at their very doorsteps.

Structures, such as fences, have the potential to become habitats for wildlife. They provide certain habitat features that allow species to invade and to exist in areas that would be otherwise unsuitable. This effect is particularly pronounced in the Great Basin where the terrain is relatively gentle over vast expanses and the structural diversity of the vegetation is relatively simple.

In the wildlife sense, such structures may be thought of as manmade habitats (Appendix 1). A land manager should consider this aspect of old structures when decisions are made about their future.

It is the purpose of this discussion to point out wildlife habitat values of manmade structures in rangelands, and to make suggestions about how such habitat values may be enhanced.

Abandoned Homesteads

Abandoned homesteads have been and are being destroyed because of their ramshackle condition, hazard to humans or livestock, and other reasons. But, destruction of such historic sites on public lands appears to contradict the intent of the Historic Preservation Act (1966: 915) which states:

> . . .That Congress finds and declares—
>
> (a) That the spirit and direction of the Nation are founded upon and reflected in its historic past;
>
> (b) That the historical and cultural foundations of the Nation should be preserved as a living part of our community life and development in order to give a sense of orientation to the American people;
>
> (c) That, in the fact of ever-increasing extensions of urban centers, highways, and residental, commercial, and industrial developments, the present governmental and nongovernmental historic preservation programs and activities are inadequate to insure

future generations a genuine opportunity to appreciate and enjoy the rich heritage of our Nation. . . .

Further, the National Environmental Policy Act (1969, p. 852), under "Title 1, Declaration of National Environmental Policy," states that:

(4) preserve important historic, cultural, and natural aspects of our heritage, and maintain, wherever possible, an environment which supports diversity and variety of individual choice. . . .

And destruction of homesteads is not in keeping with Bureau of Land Management policy (United States Department of the Interior Bureau of Land Management Manual 6231).

The most obvious management interest in abandoned homesteads is for their historical and cultural value. But they also provide wildlife habitat. Most abandoned homesteads have four features that make them valuable as habitat—buildings and associated structures, introduced vegetation, a permanent source of water, and a creation of diversity in an otherwise homogeneous habitat. Any or all of the following features may be found around these old homesteads: house and outbuildings, rock or rail fences, irrigation ditches, root cellars, primitive roads, culverts, ponds, springs, wells, ornamental trees and shrubs, fruit trees, refuse piles or pits, abandoned machinery, and fenced grave sites.

BUILDINGS

Abandoned wooden buildings (fig. 1) serve as habitat for a variety of animals (Bailey 1936, Orr 1954, Stebbins 1954, 1966). Lizards and snakes use them for sunning, shade, and shelter, as places to feed, and as reproductive sites. Screech owls (*Otus asio*) use building-interiors for roosting and rearing young. Barn swallows (*Hirundo rustica*) nest inside buildings (fig. 2), and cliff swallows (*Petrochelidon pyrrhonota*) construct nests on the outer walls. Common flickers (*Colaptes auratus*) often peck holes through the outer wall of "double-walled" buildings and nest in the interspaces (fig. 3). These "cavities" are secondarily inhabited by bats (Orr 1954), chipmunks (*Eutamias* spp.), deer mice (*Peromyscus maniculatus*), woodrats (*Neotoma* spp.), American kestrels (*Falco sparverius*), and starlings (*Sturnus vulgaris*).

Bats use the interior of old buildings as night roosts where they hangup while digesting their food; bats may also use them as sites in which to hibernate (Barbour and Davis 1969, Orr 1954). Buildings which are located in cool sites and have tarpaper siding may have bats roosting under the tarpaper during the day.

Figure 1.—Abandoned wooden buildings (homesteads) serve as habitat for a variety of wildlife species. The introduced vegetation is particularly important to birds. (Bureau of Land Management photograph)

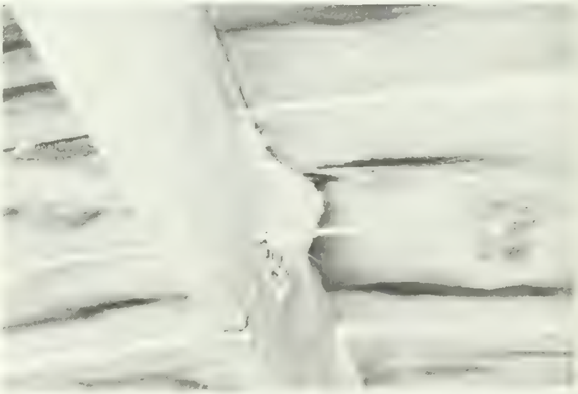

Figure 2.—A barn swallow (*Hirundo rustica*) nest on a beam inside an abandoned wooden building. (Chris Maser photograph)

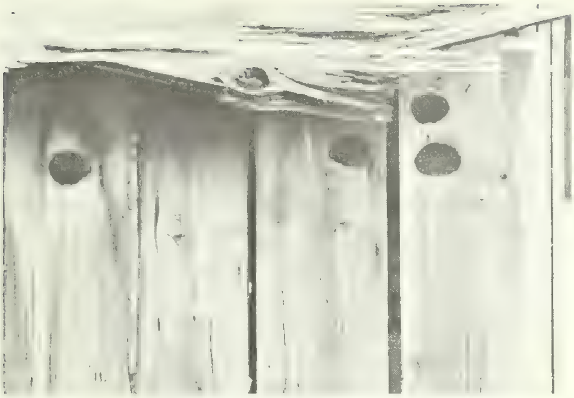

Figure 3.—Common flickers (*Colaptes auratus*) often peck holes through the outer wall of "double-walled" buildings and nest in the interspaces. In this case, the holes are in the wall under the overhang of the roof. These "cavities" are secondarily inhabited by other species of wildlife. (Chris Maser photograph)

Figure 4.—A deer mouse (*Peromyscus maniculatus*) nest within the top of the door casing of an abandoned homestead. (Chris Maser photograph)

Larger animals, such as mountain cottontail rabbits (*Sylvilagus nuttalli*), ground squirrels (*Spermophilus* spp.), yellow-bellied marmots (*Marmota flaviventris*), long-tailed weasels (*Mustela frenata*), striped skunks (*Mephitis mephitis*), spotted skunks (*Spilogale putorius*), and badgers (*Taxidea taxus*), live under buildings, whereas deer mice (fig. 4) and woodrats (fig. 5) frequent all stories. Even collapsed wooden buildings and piles of wooden fence posts are used as shelter and as sites for rearing young by lizards, snakes, mountain cottontail rabbits, yellow-bellied marmots, ground squirrels, woodrats, deer mice, long-tailed weasels, and others.

Abandoned wooden buildings are used as hiding and thermal cover, and as sites for reproduction, feeding, hibernation, sunning, and as elevated lookouts by a variety of wildlife. Buildings constructed of rock (fig. 6) are more important than are wooden buildings as habitat for lizards, snakes, and digging rodents, such as ground squirrels and marmots, because they more closely simulate their natural habitat.

Figure 5.—Bushy-tailed woodrat (*Neotoma Cinerea*) nest in the attic of an abandoned homestead. (Chris Maser photograph)

Figure 6.—Buildings constructed of rock are important as habitat for lizards, snakes, and digging rodents because they more closely simulate their natural habitat. (Bureau of Land Management photograph)

The concentration of animals is, in turn, attractive to predators. Predators frequently found in association with abandoned buildings include hawks, owls, long-tailed weasels, badgers, coyotes (*Canis latrans*), and bobcats (*Lynx rufus*).

INTRODUCED VEGETATION

Homesteaders often planted shade and fruit trees and shrubs. Many abandoned home sites still have Lombardy poplars (*Populus nigra*) (fig. 7), white poplars (*Populus alba*) (fig. 8), cottonwoods (*Populus* spp.), and black locusts (*Robinia pseudoacacia*) growing around them. These trees stand out in stark contrast to a generally treeless landscape and are commonly used as perching sites and nesting locations for such birds as northern orioles (*Icterus galbula*), western kingbirds (*Tyrannus verticalis*), black-billed magpies (*Pica pica*) (fig. 9), black-headed grosbeaks (*Pheucticus melanocephalus*), red-tailed hawks (*Buteo jamaicensis*) (fig. 10), ferruginous hawks (*Buteo regalis*), golden eagles (*Aquila chrysaetos*), great

Figure 7.—The tall, narrow trees are Lombardy poplars (*Populus nigra*). They are not self-producing. (Bureau of Land Management photograph)

Figure 8.—White poplars (*Populus alba*) are self-producing. Note the young trees in the lower right corner. (Chris Maser photograph)

Figure 9.—Black-billed magpies (*Pica pica*) often perch and nest in trees around abandoned homesteads. (Robert R. Kindschy photograph)

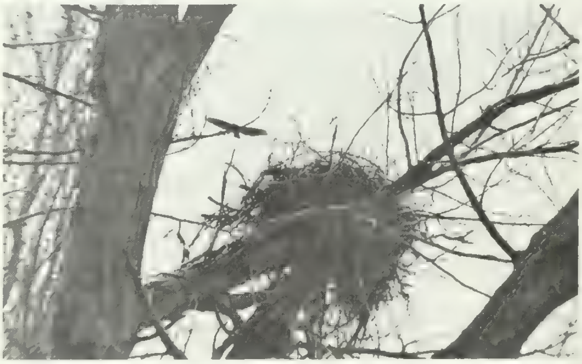

Figure 10.—Red-tailed hawks (*Buteo jamaicensis*) are one of the raptors that nest around abandoned homesteads. (Robert R. Kindschy photograph)

horned owls (*Bubo virginianus*), long-eared owls (*Asio otus*), and flickers (Marion and Ryder 1975, Olendorff and Stoddart 1974, Schnell 1968, Seibert et al. 1976, Smith et al. 1972, Snow 1974a, Woffinden 1975). Common flickers excavate cavities in dead trees and in dead limbs on live trees. The abandoned nest-cavities are secondarily used by mountain bluebirds (*Sialia currucoides*), western bluebirds (*Sialia mexicana*), starlings, violet-green swallows (*Tachycineta thalassina*), American kestrels, and bats. In addition, hoary bats (*Lasiurus cinereus*) roost in the foliage of these trees during their spring and fall migrations (Bailey 1936, Constantine 1959, 1966). Many homesteads also have shrubs around them—some introduced, some native. Shrubs are used for nesting by such birds as gray flycatchers (*Empidonax wrightii*), house finches (*Carpodacus mexicanus*), and lazuli buntings (*Passerina amoena*). The presence of trees and shrubs greatly increases habitat diversity. Trees are particularly important in this regard (fig. 11).

Figure 11.—The trees that were planted around old homesteads are particularly important as habitat for nesting birds. (Bureau of Land Management photograph by M. Hurd)

WATER

Homesteads were normally located near a source of permanent water, usually a spring, stream, or river. Springs that were made into reservoirs, but not maintained, often developed riparian and aquatic vegetation (fig. 12). Some reservoirs contain fish and bullfrogs (*Rana catesbeiana*). Western harvest mice

Figure 12.—Springs that were made into reservoirs, but then were no longer maintained, often developed riparian and aquatic vegetation. (Bureau of Land Management photograph by Robert R. Kindschy)

(*Reithrodontomys megalotis*) and montane voles (*Microtus montanus*) may occupy the marshy areas; and yellow warblers (*Dendroica petechia*), short-eared owls (*Asio flammeus*), American avocets (*Recurvirostra americana*), red-winged blackbirds (*Agelaius phoeniceus*), killdeer (*Charadrius vociferus*), mallards (*Anus platyrhynchos*) (fig. 13), cinnamon teal (*Anus cyanoptera*), marsh hawks (*Circus cyaneus*) (fig. 14), and other birds nest in and around the riparian vegetation (Evans and Kerbs 1977, Greenwell 1952). In addition, migratory waterfowl are frequent visitors during the spring and fall.

Figure 13.—Mallards (*Anus platyrhynchos*) can be found nesting in marshy areas surrounding homestead reservoirs that are no longer maintained.

Figure 14.—Marsh hawks (*Circus cyaneus*) also nest in marshy areas surrounding homestead reservoirs that are no longer maintained.

The presence of the water attracts many animals. Tracks of California quail (*Lophortyx californicus*), rabbits, mule deer (*Odocoileus hemionus*), pronghorns (*Antilocapra americana*), coyotes, and bobcats are often observed near water.

DIVERSITY

Buildings, trees, shrubs, and permanent sources of water associated with abandoned homesteads provide three essential habitat components—food, water, and cover—in a relatively small area. This combination contrasts dramatically with the surrounding, comparatively sterile, habitats (fig. 15). In so doing, they add greatly to the diversity and richness of an area. Abandoned homesites, then, provide habitat for species that would be otherwise scarce or absent in the locale. They also act to concentrate a number of common species.

Figure 15.—Old homesteads contrast dramatically with the surrounding, relatively homogeneous rangeland habitats. (Bureau of Land Management photograph by Robert R. Kindschy)

Some habitat attributes created by abandoned homesteads are relatively unstable, and time exacts a toll on many of them. Wooden buildings are dismantled, vandalized, burned, or gradually deteriorate. Some of the introduced vegetation, such as Lombardy poplar, is not self-reproducing and gradually dies.

Diversity created by abandoned homesteads is long lasting but changes over time. For example, vegetation, such as white poplar, is self-perpetuating and can remain more or less intact for over a century. The source of water, however, preceded the homestead and will outlast it (fig. 16). These abandoned works of man, therefore, enhance the habitat for a variety of species of wildlife for a time, allowing some to live in areas that otherwise would be unsuitable.

Roads and Bridges

Unpaved roads are highly visible features of managed rangelands; there are thousands of miles of such roads in the Great Basin. The terrain crossed by some roads necessitates the building of bridges. Although roads and bridges improve or create habitat for some species of wildlife, they degrade or destroy habitat for others. This statement may also apply to paved roads (Leedy 1975, Leedy et al. 1975).

ROADS

Although there are some positive effects of roads on some wildlife species, in general, roads have adverse effects on the broad spectrum of wildlife regardless of where or how they are constructed (Oxley et al. 1974). Adverse effects are compounded when roads are built in or adjacent to riparian zones.

The positive habitat values of rangeland roads lie primarily in their design and con-

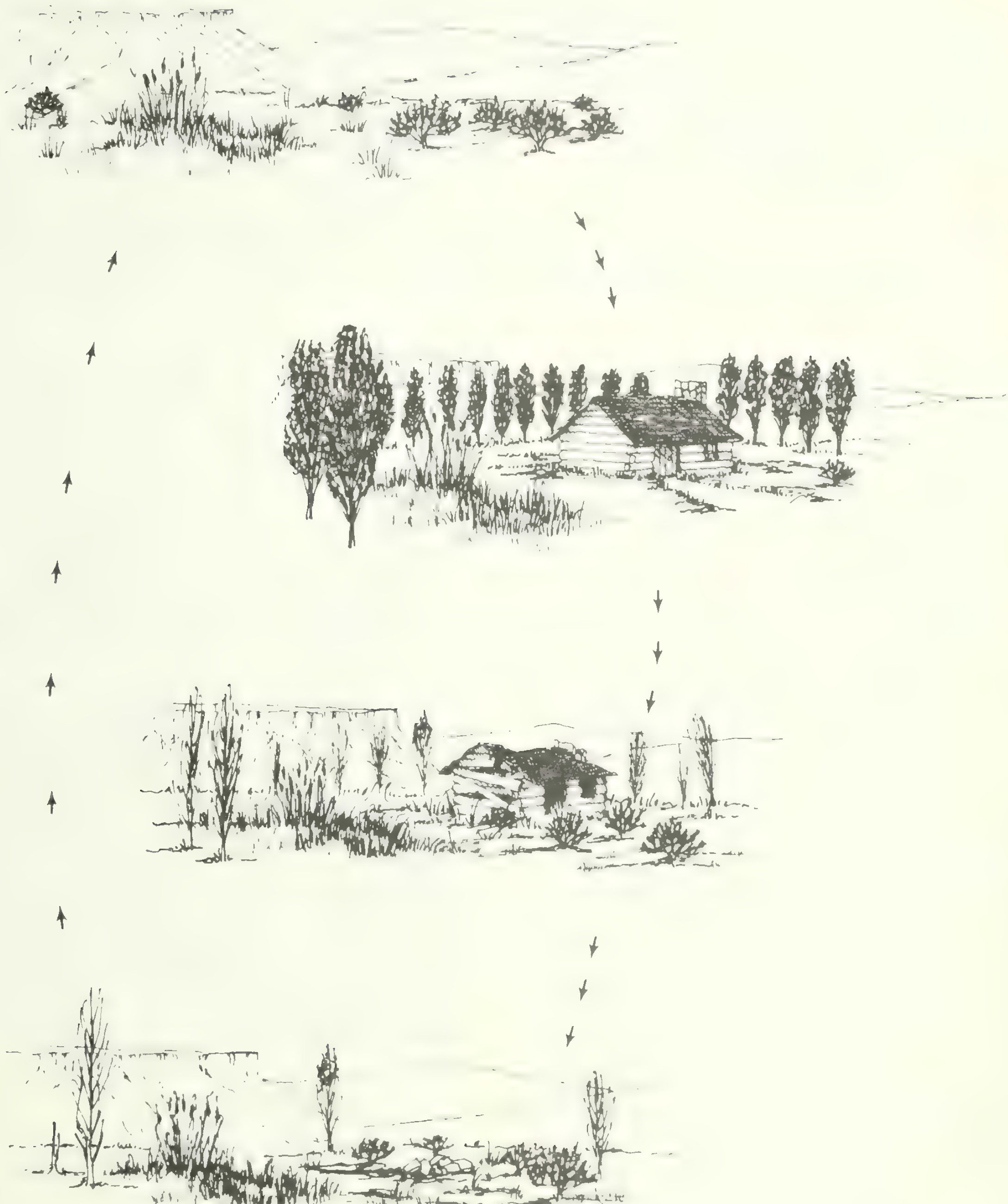

Figure 16.—Habitat diversity created by abandoned homesteads is long lasting and changes over time. Ultimately, the source of water that preceded the homestead will outlast it.

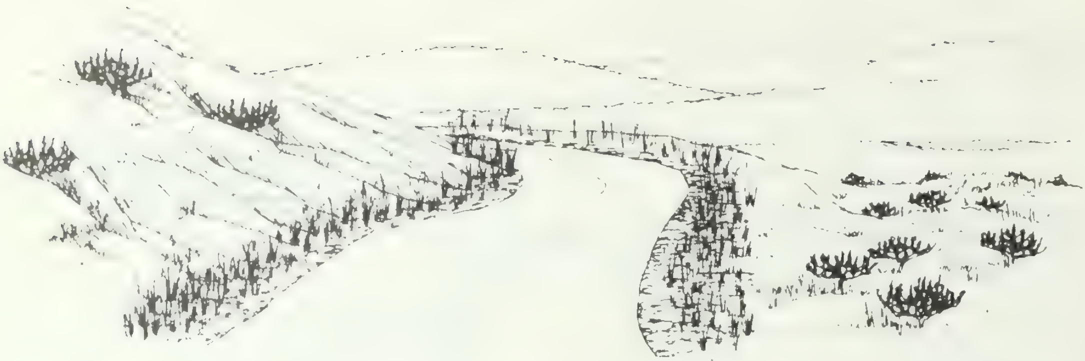

Figure 17.—Roadbanks and roadsides often enable a type of vegetation to become established that differs from that of the surrounding country, creating habitat diversity and edge-effect.

struction. Roadbanks cut into uneven terrain may require stabilization to prevent erosion, but roadsides through even terrain seldom need to be stabilized. Roadbanks and roadsides often enable a type of vegetation to become established that differs from that of the surrounding country, creating habitat diversity and edge-effect (fig. 17).

Habitat changes may be produced by exposure of several soil horizons of different textures, removal of top soil, piles of loose soil and rock, creation of moister conditions in borrow ditches and pits, installation of culverts, fertilization of cuts and fills, seeding raw banks, etc. Such alterations are particularly important as habitat where conditions are created that did not previously exist and there are wildlife species that can exploit them.

These areas are often "colonized" by ground squirrels (*Spermophilus* spp.), pocket mice (*Perognathus* spp.), kangaroo rats (*Dipodomys* spp.), voles (*Microtus* spp.), rabbits, and hares (*Lepus* spp.) (Douglas and Johnson 1972), and may act as routes of dispersal from one area to another by forming a physical link of suitable habitat through otherwise uninhabitable terrain. For example, Getz et al. (1978) wrote:

> Roadsides that provide habitats different from those occurring in adjacent areas are potential avenues of dispersal for various groups of animals. In particular, this applies to those roadsides that have dense grassy vegetation. Such roadsides provide dispersal routes for grassland species. . . .

A somewhat different set of circumstances applies to minimum standard roads through flat terrain in areas of the Great Basin. In this case, a roadbed is often lower than the "bank" because the debris (soil and rocks) is simply pushed aside with a bulldozer, creating small cuts and ridges along the road's edge (figs. 18 and 19). Soil in these ridges is often better drained and remains more friable than does that of the surrounding flatlands, particularly when much clay is present. The combination of better drainage and greater friability allows animals, such as kangaroo rats, which are relatively poor diggers, to live in and disperse along the soil ridges. This is especially important when the surrounding flatland soil is saturated with water during the winter or when it is too hard for them to dig through during the summer. Soil ridges often are nearly free of perennial vegetation and are gradually built up through additional soil deposits during road maintenance activities, thus providing a well-defined habitat.

At times, construction results in piles of debris (soil, rocks, and brush) along a road. These piles become inhabited by animals such as ground squirrels, kangaroo rats, pocket mice, harvest mice, deer mice, and sage voles (*Lagurus curtatus*). Although the piles offer elevated sites with better drainage and easier digging, they are usually scattered in distribution and may take longer to be occupied. Most of the debris piles seem to be unaffected by

Figure 18.—Construction of minimum standard roads through flat terrain may create small roadbanks, thereby adding to habitat diversity. (Bureau of Land Management photograph)

Figure 19.—Construction of minimum standard roads through flat terrain may create small ridges of soil. Soil in these ridges is often better drained and remains more friable than does that of the surrounding flatlands, making it good habitat for small mammals, such as the Ord kangaroo rat (*Dipodomys ordi*). (Chris Maser photograph)

Figure 20.—Road construction with a bulldozer through rocky soil—especially soil containing large rocks and boulders—creates a ridge strewn with large individual rocks or clusters of big rocks. Mantled ground squirrels (*Spermophilus lateralis*) and yellow-bellied marmots (*Marmota flaviventris*) are closely associated with large rocks which serve as elevated lookouts, and large roadside rocks have allowed both rodents to survive in and disperse through otherwise unsuitable habitats. (Chris Maser photograph)

road maintenance and gradually blend into the surrounding landscape. As they become overgrown with vegetation, they gradually lose their habitat-qualities for kangaroo rats, but become better habitat for mice and voles.

Due to their scattered distribution, debris piles appear to be less important as dispersal routes than do the soil ridges.

Talus formations are mimicked by large rock and boulder ridges and land-fills created during road construction. This type of roadside talus, which may be inhabited by marmots, ground squirrels, woodrats, mice, weasels, and other animals, is normally restricted in distribution. On the other hand, road construction with a bulldozer through rocky soil—especially soil containing large rocks and boulders—creates a ridge strewn with large individual rocks or clusters of big rocks (fig. 20). These talus-like rows of large rocks are used by lizards, marmots, and mantled ground squir-

rels (*Spermophilus lateralis*). Mantled ground squirrels and yellow-bellied marmots are closely associated with large rocks which serve as elevated lookouts, and large roadside rocks have allowed both rodents to survive in and disperse through otherwise unsuitable habitats.

The occupancy of these roadside habitats by reptiles and small mammals provides prey for predators and food for scavengers. The combination of animals and vehicular traffic produces a situation where many animals are killed by cars or by shooting from cars (Case 1978, Oxley et al. 1974). Consequently, there seems to be a concentration of predators and scavengers along such roads, including snakes, hawks, owls, turkey vultures (*Cathartes aura*), common crows (*Corvus brachyrhynchos*), common ravens (*Corvus corax*), black-billed magpies, coyotes, and long-tailed weasels.

Where road construction and maintenance creates ditches, water often collects and remains available to wildlife for varying periods following rain storms. This frequently creates areas where the vegetation receives greater than normal moisture and in turn produces more biomass that remains green longer. In rare circumstances, the collection of water within borrow pits and ditches forms areas where aquatic or riparian zone vegetation may be found. These more mesic conditions in a typically xeric landscape contribute to diversity and are often attractive to wildlife for water, food, and cover.

For the broad spectrum of wildlife, on the other hand, roads largely destroy habitat and often promote soil erosion (Kitchings et al. 1974), but their greatest long-term impact on wildlife is increased human access and increased use of previously remote areas (Albrecht and Smith 1977, Davey 1974, Snyder et al. 1976). Greater vehicular access, unless carefully managed, intensifies fishing, hunting, and trapping pressures on animals, such as Alvord cutthroat trout (*Salmo clarki* subspecies), jackrabbits (fig. 21), ground squirrels, coyotes, badgers, bobcats (fig. 22), pronghorns, and mule deer.

Increased access also allows these pressures to be more evenly distributed. There is

Figure 21.—Black-tailed jackrabbits (*Lepus californicus*) are often hunted for sport; increased vehicular access into an area will intensify the hunting pressures on this species and on others. (Robert R. Kindschy photograph)

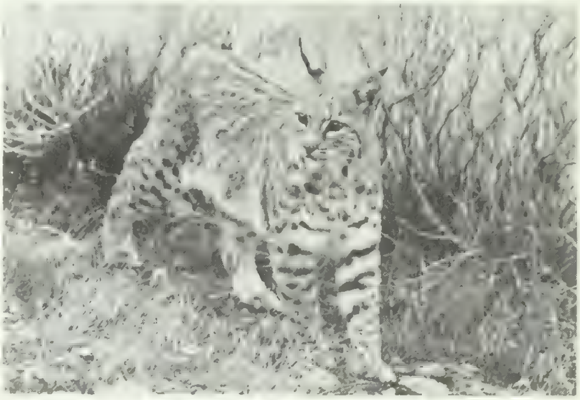

Figure 22.—Greater vehicular access, unless carefully managed, intensifies trapping pressures on fur-bearing mammals, such as the bobcat (*Lynx rufus*). (Robert R. Kindschy photograph)

little doubt that access augments the potential for enjoyment and exploitation of the wildlife resource, but this can be good or bad depending on the wildlife management objective and the intensity of the management, including enforcement of regulations. Improved access, however, is seldom related to a wildlife management objective. The impacts on wildlife, therefore, are apt to be negative.

Greater access also intensifies harassment of species, such as the sage grouse (*Centrocercus urophasianus*), ferruginous hawk (Olendorff and Stoddart 1974, Snow 1974a), prairie falcon (*Falco mexicanus*) (Parker 1973, Snow

1974b), Peregrine falcon (*Falco peregrinus*)—listed as endangered—(Federal Register 1976, Porter et al. 1973, Snow 1972), and the golden eagle (Snow 1973). For example, Ellis et al. (1969) documented a loss of 30 raptors along a 19-kilometer (12 mi) segment of a powerline. Fourteen of the birds were golden eagles, and most of the carcasses had bullet wounds. Mortality by shooting appears to occur most frequently when powerlines and roads are within 183 meters (600 ft) of each other.

BRIDGES

Although bridge construction alters the habitat at the site, bridges may produce new wildlife habitat-values, depending on the type of bridge. Bridges of creosote-impregnated wood exhibit little or no value as wildlife habitat (fig. 23). Unimpregnated, wooden bridges appear to have limited value to nesting swallows and roosting bats, but these bridges tend to vibrate. Traffic on such bridges is quite noisy and creates dust. When wooden bridges are abandoned, however, they become more valuable as wildlife habitat. The creosote is leached away over time and the absence of traffic reduces the disturbance to wildlife.

On the other hand, traffic over concrete bridges (fig. 23) is relatively quiet when compared to that crossing wooden bridges. Concrete bridges do not allow dust to sift through, and in addition produce shade, a cool microclimate, and simulate cliffs and caves. The concrete surface provides a structure which allows barn swallows and cliff swallows to build their nests on the suspension beams. Some species of bats, such as little brown myotis (*Myotis lucifugus*), Yuma myotis (*Myotis yumanensis*), California myotis (*Myotis californicus*), big brown bats (*Eptesicus fuscus*), and pallid bats (*Antrozous pallidus*), use the concrete surfaces under bridges as night-roosts (Greenhall and Paradiso 1968, Maser[1], Orr 1954). When available, suitable cracks and crevices in the concrete are used as day-roosts and sites for rearing young by such species as the pallid bat (Krutzsch 1946, Orr 1954, Storer 1931).

In addition, bridges—especially concrete bridges—produce a cool microclimate that is attractive to flying insects. Such insects, in turn, provide a food source for the insectivorous birds and bats that are associated with the bridges.

[1]Maser, Chris. Unpublished data on file at the Puget Sound Museum of Natural History, University of Puget Sound, Tacoma, Washington.

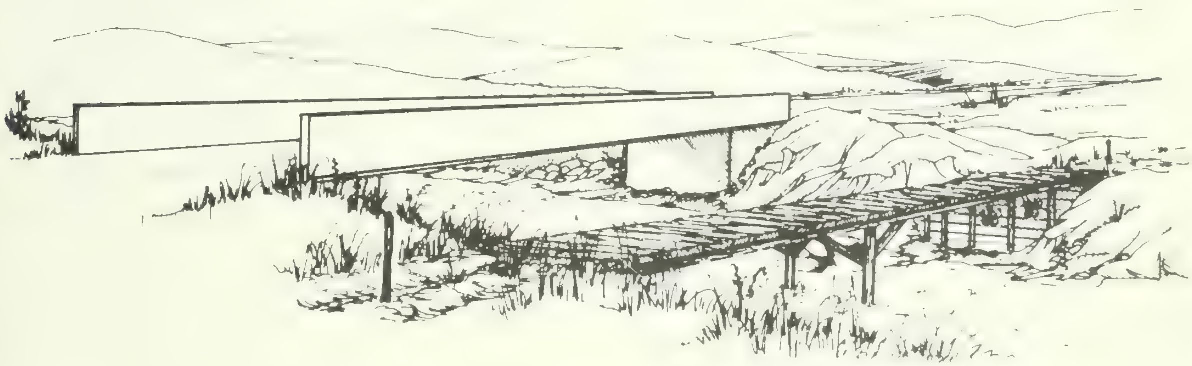

Figure 23.—Bridges of creosote-impregnated wood exhibit little or no value as wildlife habitat. They are noisy and dusty. Concrete bridges, on the other hand, are relatively quiet and do not allow dust to sift through. In addition, they produce shade, a cool microclimate, and simulate cliffs and caves. If a bridge (wooden or concrete) with well-established wildlife use is to be replaced, it may be desirable to construct the new bridge alongside of the old one, retaining the old bridge as wildlife habitat.

Rock Walls, Rock Jacks, Rock Cribs, and Sheepherder Monuments

Due to their mode of construction—essentially loose piles of large, irregular rocks—rock walls, rock jacks, rock cribs, and sheepherder monuments all simulate talus. These rock piles are honey-combed with protected spaces which provide shelter from the elements for a variety of species. The spaces are sheltered from winter winds thereby reducing the chill factor, but on the other hand, these spaces are much cooler than surrounding areas in summer.

Such spaces are used by a variety of prey species—vertebrate and invertebrate—which in turn are consumed by predators. The animal biomass associated with these structures seems to be much greater than in similar areas lacking them (Sinclair et al. 1967).

ROCK WALLS

Walls constructed of rock, usually lava, provide stable habitats for a variety of animals (Lustig 1976, Sinclair et al. 1967) (fig. 24). Lizards, such as western fence lizards (*Sceloporus occidentalis*) and side-blotched lizards (*Uta stansburiana*); snakes, such as blue racers (*Coluber constrictor*), gopher snakes (*Pituophis melanoleucus*), and western rattlesnakes (*Crotalus viridis*) (fig. 25); birds, such as rock wrens (*Salpinctes obsoletus*), canyon wrens (*Catherpes mexicanus*), and Say's phoebes (*Sayornis saya*); and mammals, such as mountain cottontail rabbits, chipmunks, yellow-bellied marmots, ground squirrels, deer mice, canyon mice (*Peromyscus crinitus*), woodrats, long-tailed weasels, and skunks, all use rock walls for feeding and for reproduction (Bailey 1936, Burt and Grossenheider 1964, Maser [unpublished data][2], Peterson 1961, Stebbins 1954, 1966). Some animals, such as lizards, snakes, and ground squirrels, spend much time sunning themselves on the walls during the spring, summer, and fall, and hibernate in or beneath the walls during the winter. These,

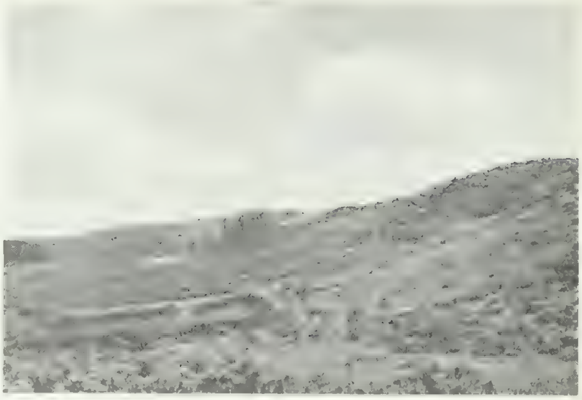

Figure 24.—Rock walls, usually made of lava, provide stable habitats for a variety of animals. (Bureau of Land Management photograph)

Figure 25.—The western rattlesnake (*Crotalus viridis*) is a frequent inhabitant of rock walls. (Bureau of Land Management photograph by Grant Baugh)

and other animals, also depend upon the walls as elevated lookouts.

ROCK JACKS

Rock jacks (fig. 26) are usually built so that the rocks are initially elevated off of the ground. When the supporting wooden structure deteriorates, the pile of rocks has a habitat function similar to that of the rock cribs discussed next. The distance above ground determines which animals can seek shelter

[2]See footnote 1.

Figure 26.—A rock jack is usually built so that the rocks are initially elevated off of the ground. (Chris Maser photograph)

beneath them. For example, a rock jack in which the bottom rocks are 15 cm (6 in) above the ground creates a large enough space for a mountain cottontail, whereas a Townsend ground squirrel (*Spermophilus townsendi*) can utilize a space that is only 10 cm (4 in) high, and a rattlesnake can use a 5-cm (2-in) space.

Rock jacks constructed with large rocks, 30 to 60 cm (12 to 34 in) in diameter, show greater use by wildlife (reptiles, birds, and mammals) than do those composed of rocks less than 30 cm (12 in).

Wildlife uses of rock jacks are varied; they include: feeding, reproduction, escape, shade, shelter from wind, sunning, perching, and lookouts. Since rock jacks are used to stabilize fences, they are incorporated at varying intervals, usually 30 to 50 meters (98 to 164 ft) into kilometers (miles) of livestock fence. As a result, they form dispersal routes through otherwise uninhabitable country for animals, such as the desert woodrat (*Neotoma lepida*) (fig. 27).

ROCK CRIBS

Rock cribs (figs. 28 and 29) offer essentially the same function as wildlife habitat as do rock jacks, but for a smaller variety of species. Since rock cribs rest on the ground surface, wildlife use is limited to those species that can climb within or on top of the rocks. Cottontail rabbits, for example, are largely eliminated as

Figure 27.—Since rock jacks are used to stabilize fences, they are incorporated into kilometers (miles) of livestock fence. As a result, they form dispersal routes through otherwise uninhabitable terrain. In this case a desert woodrat (*Neotoma lepida*) is inhabiting such a rock jack, as evidenced by its nest. (Chris Maser photograph)

users of rock cribs, but lizards, snakes, woodrats, ground squirrels, and weasels have free access to the security of a crib. As with rock jacks, the size of the rocks used in construction also determines which species can use a rock crib. Albeit, small rocks, 15 to 20 cm (6 to 8 in) in diameter, give an appearance of "neatness"

Figure 28.—A wooden rock crib, if constructed with large rocks, has essentially the same function as wildlife habitat as does a rock jack. Since the rocks are not initially elevated off of the ground, however, a few of the larger animals, such as the mountain cottontail rabbit (*Sylvilagus nuttalli*), may be excluded from inhabiting wooden rock cribs. (Chris Maser photograph)

Figure 29.—A wire rock crib can be used as habitat by animals as large as Belding ground squirrels (*Spermophilus beldingi*). Larger animals are excluded, however, by the smaller-sized rocks used in these cribs and by the diameter of the wire mesh. (Chris Maser photograph)

Figure 31.—Sheep-herder monuments consist of piles of rocks. (Bureau of Land Management photograph)

Figure 32.—Sheep-herder monuments are often located on or near the tops of hills and serve as perching sites for raptors, such as golden eagles (*Aquila chrysaetos*). (Bureau of Land Management photograph)

and are sometimes thought to be more esthetically pleasing, the "neatness" and "esthetics" of a crib made with small rocks diminishes its usefulness to wildlife (fig. 30).

Rock cribs are also used to stabilize fences and may create routes of dispersal for some species of wildlife.

Figure 30.—A "neat" or "esthetically pleasing" wire rock crib is made with small rocks which lack the large spaces between them, and a small-mesh wire is used to contain the rocks. This combination of construction materials can eliminate all but the smaller animals, such as deer mice (*Peromyscus maniculatus*) or desert woodrats (*Neotoma lepida*), from using such a rock crib as habitat. (Bureau of Land Management photograph by A. K. Majors)

SHEEPHERDER MONUMENTS

Sheepherder monuments (figs. 31 and 32), which are more or less randomly distributed, consist of piles of rocks. They serve essentially

the same habitat function for wildlife as do rock jacks and rock cribs, but do not form dispersal routes. Often located on hill tops, they serve as perching sites for raptors, such as golden eagles.

Wooden Corrals and Fences

Wooden corrals (figs. 33 and 34), and fences with wooden posts (fig. 35) appear to belong largely to past decades. Most new fences are constructed with steel posts.

Although often associated with old homesteads, wooden fences also may be isolated from such sites. Those few that remain are used by western fence lizards for sunning and by chipmunks, raptors, shrikes (*Lanius* spp.), and other birds as lookouts. In addition, shade from these posts is sought by lizards, snakes, small birds, and small mammals to escape the heat on hot cloudless days.

Figure 33.—Wooden corrals are used as perches by many birds. (Chris Maser photograph)

Figure 34.—In addition to providing perches for birds, wood corrals can also provide animals with shade and protection from wind. (Chris Maser photograph)

Figure 35.—The wooden posts in this fence can be used as perches by birds and as shade by small, ground-dwelling animals on hot, cloudless days. (Bureau of Land Management photograph)

Cavities are often found in decaying fence posts and are used by small cavity-nesting birds such as bluebirds, house wrens (*Troglodytes aedon*), swallows, chickadees (*Parus* spp.), and mammals such as bats, deer mice, and chipmunks. These sources of nesting sites allowed some species to temporarily invade otherwise unsuitable habitats, and a species'

Figure 36.—Fences frequently occur along edges between vegetation of different types or different structural conditions. Fences, in this sense, created and/or maintain habitat diversity and often are particularly rich in wildlife. (Bureau of Land Management photograph)

decline in such areas may be related to the gradual loss of that habitat.

Fences frequently occur along edges between vegetation of various types or in different stages of development (fig. 36). As such, they are of particular value to some species and are often particularly rich in wildlife.

Powerlines

Powerlines have become common and, perhaps, inevitable features of the landscape. They have potential as wildlife habitat and have other influences on wildlife. The impacts of powerlines on wildlife depend on: (1) size of lines, poles, and towers, (2) voltage of lines, (3) location, size, and shape of rights-of-way, and (4) the type of vegetation management within rights-of-way.

POWERLINES, POLES, AND TOWERS

Raptors, such as golden eagles, red-tailed hawks, and ferruginous hawks, use powerlines, poles, and towers as sites for perching and nesting (Gilmer and Wiehe 1977, Marion and Ryder 1975, Olendorff 1972, Olendorff and Stoddart 1974). In early years, small distribution lines, such as the Rural Electrification Administration (REA) type, electrocuted many raptors, especially golden eagles (Boeker 1974, Boeker and Nickerson 1975, Fitzner 1975, Harrison 1963, Olendorff 1972, Smith and Murphy 1972, Snow 1973). In recent years, however, powerlines, poles, and towers have been modified not only to make lines safe for raptors but also to adapt poles and towers as sites for perching and for nesting (Miller et al. 1975, Nelson and Nelson 1977). Thus, in some cases, it has been possible to turn a wildlife liability into an asset.

In addition, many birds are killed when they collide with towers and lines, particularly small-diameter, closely spaced transmission and secondary distribution lines (Anderson 1978, Anderson et al. 1975, Kemper 1964, Krapu 1974, Scott et al. 1972, Stout and Cornwell 1976). Satisfactory solutions to this problem have yet to be found.

Extra high voltage power lines (500 KV+) produce a corona effect—ozone production, noise, and flashes of light. Although the unusual olfactory, auditory, and visual stimuli of the corona effect may be adverse to wildlife (Kline 1971, Young 1973), such adversity has not been conclusively proven (Goodwin 1975).

Extra high voltage power lines (500 KV+) also produce electric and magnetic field effects. These fields can induce voltages and currents in plants and animals near such lines (Jack Lee, personal communication, Miller and Kaufman 1978). But thus far, no adversity to wildlife has been demonstrated by the electric field effect (Bankoske et al. 1976).

RIGHTS-OF-WAY

Managed rights-of-way are beneficial to some wildlife and detrimental to others. The two primary features of rights-of-way that influence wildlife are alteration of existing vegetation and increased human access via roads.

In many areas, the most obvious feature of a right-of-way is alteration of the habitat within it. Tall vegetation, such as trees and shrubs, are initially eliminated. Subsequent management may maintain the vegetation in the right-of-way in an earlier, lower structural condition (fig. 37). If efforts are not made to remove trees and shrubs as they reappear, the site may return to its original condition. Thus, plant species composition and diversity may not be significantly affected over time (Ludwig et al. 1977, Potter and Krenetsky 1967).

Where heavy shrub growth is removed or trees are felled to clear a right-of-way, there should be a corresponding increase in grasses and forbs (Barney and Frishknecht 1974, Clary 1974, Erdman 1970, Ludwig et al. 1977). Although increases may be related to an increased amount of sunlight and consequent drying of the site (Jameson 1970), there is considerable annual variability in herbage production which is presumably a product of precipitation. If undisturbed, a site will progress by stages back to its original structural condition (Barney and Frishknecht 1974).

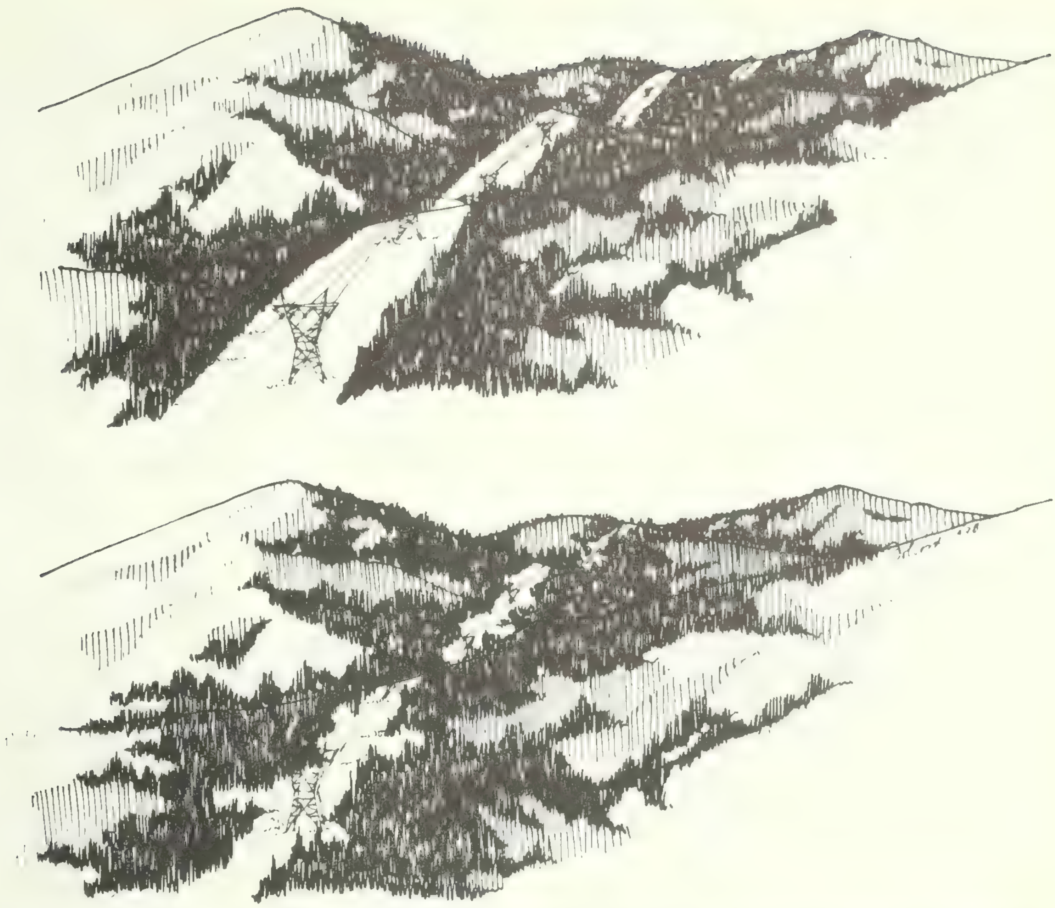

Figure 37.—In many areas, the most obvious feature of a right-of-way is alteration of the habitat within it. Once established, subsequent management may maintain the vegetation in a right-of-way in an earlier, lower structural condition. Powerline rights-of-way can be designed with irregular borders to enhance edge effect and to make them as aesthetically pleasing as possible.

Right-of-way construction can either create or deplete habitat diversity. For example, a right-of-way through a small, isolated stand of juniper will eliminate a locally rare habitat, reduce contrast, eliminate edge, and thereby reduce habitat diversity. Whereas a right-of-way through an extensive stand of juniper will open up some of the stand, create a new structural condition, produce edge, and thereby increase habitat diversity.

Where diversity has been created by a right-of-way, Anderson et al. (1977) found that bird species diversity was correlated with the width of the right-of-way. This was due to habitat alteration of sufficient size to support those species of birds that required either the type of habitat created, or the edge-effect, or both. There is some evidence to indicate that mammals react to rights-of-way in a similar fashion (Goodwin 1975, Schreiber and Graves 1977).

It is doubtful that maintenance of powerline rights-of-way in rangelands will require extensive manipulation of vegetation since most plant communities are relatively low in structure. Where such manipulation is required, however, application of herbicides is the treatment often used.

Application of herbicides to control sagebrush (*Artemisia* spp.) in rights-of-way adversely affects some species, such as the sage sparrow (*Amphispiza belli*), Brewer's sparrow (*Spizella breweri*), and sage grouse

(Baker et al. 1976, Braun and Beck 1976, Gabrielson and Jewett 1970, Klebenow 1969, Schroeder and Sturges 1975). Treatment may not only reduce local populations of sage grouse (Klebenow 1970, Rogers 1964) but also may detrimentally affect food supplies of pronghorns and mule deer on the immediate winter range (Cole 1956, Martinka 1967, Smith 1959). Further, spraying rights-of-way for shrub control may locally reduce or eliminate forbs and arthropods that are important sources of food for some species of wildlife, such as leopard lizards (*Crotaphytus wislizeni*), blue racers, sage grouse, loggerhead shrikes (*Lanius ludovicianus*), northern grasshopper mice (*Onychomys leucogaster*), and sage voles (Martin 1970, Maser et al. 1974, Parker and Pianka 1976, Peterson 1970, Tanner and Krogh 1974). This, in turn, affects the food supply of predators, such as gopher snakes and burrowing owls (*Athene cunicularia*) (Marti 1974, Maser et al. 1971, Zarn 1974).

Maintenance of rights-of-way for powerlines, however, usually involves only a minor portion of the general area. While impacts on wildlife may be pronounced on the areas treated, the overall effect may be quite small.

The reduction of the vegetation from shrubs, trees, or both to a grass-forb condition will benefit species that are adapted to such conditions, for example, the horned lark (*Eremophila alpestris*). Rights-of-way will also provide pronounced edges between woody vegetation and largely herbaceous vegetation. Edges, in turn, are indicative of some measure of diversity in a rather homogeneous habitat.

Herbicides accomplish control of unwanted vegetation without the soil disturbance associated with mechanical methods of control. Further, because the dead plant material is usually left in place to decay, the impact on habitat structure is delayed and less severe.

The use of herbicides has been the subject of recent controversy concerning potential direct and indirect hazards to wildlife. Specific hazards involving the use of chemicals range from negligible (Bollen et al. 1970 and 1977, Montgomery and Norris 1970) to acute poisoning (Norris 1974).

Although mechanical manipulation of vegetation or the use of prescribed burning have immediate, dramatic impacts on habitat structure and may be used to accomplish the same goals as herbicide treatments, they avoid the controversy over herbicides.

Croplands

The purpose of this treatment is simply to note that croplands occur in the midst of managed rangelands (fig. 38). They are so different in ecological makeup that they require a totally different management viewpoint.

Figure 38.—Croplands occurring amidst managed rangelands are so different in ecological make-up that they require a totally different management viewpoint. (Bureau of Land Management photograph by Robert R. Kindschy)

De Loach (1971:225) said: ". . .the objective of agriculture is to encourage the growth of a foreign organism, a crop, at a high density and to suppress. . .organisms that might compete with it. . . ." Kennedy (1968) suggested that agriculture and conservation are no longer compatible concepts and should be considered separately.

> "When man dug holes here and there and planted a few seeds for his food, ample diversity of species remained, but this resulted in small crop yields both because of competition from other plants (weeds) and because insects, birds, and mammals all took their share of the crop" (Pimentel 1971:212).

In modern agricultural practice in North America, however, large fields are often planted with a single-species. This specialization has resulted from the economic needs and technology of a mechanized society and has created a greatly simplified environment (Pimentel 1971). Such monocultures are basically unstable and lack the checks and balances of a natural, diverse ecosystem. Agricultural crops, therefore, require constant human care (such as cultivation) and control (with insecticides, rodenticides, herbicides, or all three) if a crop is to produce as desired.

Plant and animal communities that surround croplands exert a constant, often negative, influence on production. When native plants and animals use agricultural crops as habitat, they are normally termed pests; however, "Pests exist only in man's own view of nature and their existence results. . .from his. . .resource management practices" (Pimentel 1971:211).

Small, diversified family farms were excellent habitat for wildlife. They provided increased structural diversity, and therefore, increased habitat diversity through a good mix of food, cover, and water within surrounding, rather homogeneous rangelands. The many small, irregular fields with a variety of crops created an abundance of structurally diverse edges; and tillage offered a variety of soil textures for burrowing animals. Uncultivated fence-rows and ditch banks provided strips that not only acted as primary habitat for some species but also provided travel lanes between fields for other species. These situations were ideal for species, such as gopher snakes, California quail, ring-necked pheasant (*Phasianus colchicus*), voles, rabbits, weasels, skunks, and foxes (*Vulpes* spp.).

Replacement of small farms by large farms dependent on mechanization and specialized crop monocultures caused a drastic decline in wildlife habitats within and adjacent to croplands. And, because of the decreased crop stability—increased crop vulnerability—resulting from the greatly simplified "agricultural ecosystem," man is more and more inclined to view native wildlife as actual or potential "pests" to his crops.

The erratic economics of agriculture is considered to be the primary impetus behind increasing crop specialization in North America. In addition, governmental influence on modern agriculture, which has attempted to maintain low-cost food production, has largely made the small, diversified farm uneconomical. Consequently, most have disappeared. In turn, for modern agriculture to survive economically, modifications in farming strategies have been necessary, and the following changes in land use have resulted:

1. Increased specialization of farms (growing fewer crops in larger fields) caused amalgamation of small, individual fields.

2. Increased size of individual farms due to large, specialized corporate farms replacing small, diversified family farms.

3. Increased use of modern machinery that is more easily and more economically operated in large fields.

4. Increased clearing of fence rows to gain more land for agriculture (Shrubb 1970, Van Deusen 1978)—2.6 kilometers (1 mile) of fence row may occupy .2 hectare (.5 acre) (Moore et al. 1967).

5. Increased use of large, sprinkler irrigation systems that eliminate uncultivated irrigation ditches and their banks.

6. Replacement of uncultivated earthen irrigation ditch banks with concrete.

7. Federal aid to farmers through the Agricultural Stabilization and Conservation Service for various types of land "reclamation."

Although these factors reduce habitat for many species of wildlife within agricultural lands (Allen et al. 1973), they also create habitat for a few species, such as the exotic ring-necked pheasant. For example, with specialization, came larger individual fields and, therefore, extensive monocultures. The small, diversified family farms have been replaced by large, specialized corporate farms with modern machinery that can only be utilized efficiently and economically in large, single-product fields.

From the foregoing discussion, it should be recognized that where agricultural crops occur in managed rangelands, they may be primarily considered as being in conflict with most wildlife species. In some cases, these conflicts may be severe, such as heavy grazing by deer on hay crops or by rodent damage to grain crops. But agricultural lands do provide habitats for some game species that are particularly adapted to agricultural conditions—such as the exotic pheasant. In addition, some native species, such as quail and cottontail rabbits, may take advantage of edges created between cropland and rangeland.

Management Tips

ABANDONED HOMESTEADS

When considering historical and wildlife values, it is desirable to retain abandoned homesteads, regardless of their age. Not only do they add character and historical interest to the landscape but they also add wildlife habitat diversity. Although it may be uneconomical to maintain homesteads in a constant state of repair, it costs nothing to allow these habitats to remain—disintegrating slowly and naturally (fig. 39).

Allowing homesteads to disintegrate naturally is in keeping with the USDI Bureau of Land Management Manual 1602—Basic Guidance (1973: 42C-42C3d), under "Environmental Protection and Enhancement," which states that:

> c. In all land use and program decisions, protection of natural and man-made elements in the environment which have esthetic values of natural beauty, harmony, variety or uniqueness will be fully considered.
>
> d. In all land use and program decisions, protection of natural and man-made elements in the environment which contribute to the cultural heritage of human society, or to human understanding of ecological processes, will be fully considered.

Figure 39.—Although it may be uneconomical to maintain homesteads in a constant state of repair, it costs nothing to allow these habitats to remain — disintegrating slowly and naturally. Once a homestead site has been established and the introduced vegetation, such as trees and shrubs, has become part of the landscape, the site can be planned for and managed as wildlife habitat. (Bureau of Land Management photograph)

> e. If there is no cost involved, ecological, esthetic or human interest values will be protected or enhanced through careful design and execution of Bureau programs. If preservation or enhancement of these values would result in loss of other resource values or increase in program costs, the long range cost is compared to the long range results. Great weight is given to preservation of a wholesome continually productive environment for future generations.

If maintenance of a wooden homestead is a management objective, however, it would be a good idea to refer to the overview article by Rowell et al. (1977) on the preservation of log cabins.

Once a homestead site has been established and the introduced vegetation, such as trees and shrubs, has become part of the landscape, the site can be planned for and managed as wildlife habitat. Moreover, use as wildlife habitat can easily be perpetuated by scheduling the replanting of trees and shrubs to assure maintenance of the habitat over time.

If livestock are to be grazed in the vicinity of an abandoned homestead, it may be advisable to fence the livestock out of the homestead site. Such action not only will greatly prolong the site's value but also will encourage and protect the development of relatively dense vegetation, enhancing the value of the site as wildlife habitat.

It may be wise *not* to show the locations of abandoned homesteads on tourist and recreational maps, thereby eliminating much potential disturbance and vandalism.

Finally, if a management plan includes the alteration of an abandoned homestead, the site should be examined by both a wildlife biologist and a cultural resource specialist (USDI Bureau of Land Management Manual 6231). The value of these abandoned homesteads as wildlife habitat should be added to their historical value as reasons to continue their existence.

ROADS

Banks, soil ridges, and talus-like formations created by road construction form significant wildlife habitats in areas where the habitats that they mimic are naturally lacking. When and where these manmade habitats harbor uncommon wildlife or wildlife of special interest, they can be identified and managed as habitats with planned perpetuation and enhancement. It may also be desirable, under some circumstances, to purposefully create and maintain one or more such habitats in specific locations for specific species of wildlife.

BRIDGES

When possible, bridges should be constructed of concrete, masonry, or rock rather than wood; such bridges have the greatest potential as wildlife habitat. For example, the surface of the pillars and beams can be roughened so swallows will have an easier time attaching their nests and bats may gain a better purchase when roosting. Beams can have built-in ledges or bolted on planks to form nesting platforms for birds. Nesting boxes can be installed under bridges to further increase bird use. Bridges can also be designed with deep "crevices" so that bats can raise their young (fig. 40).

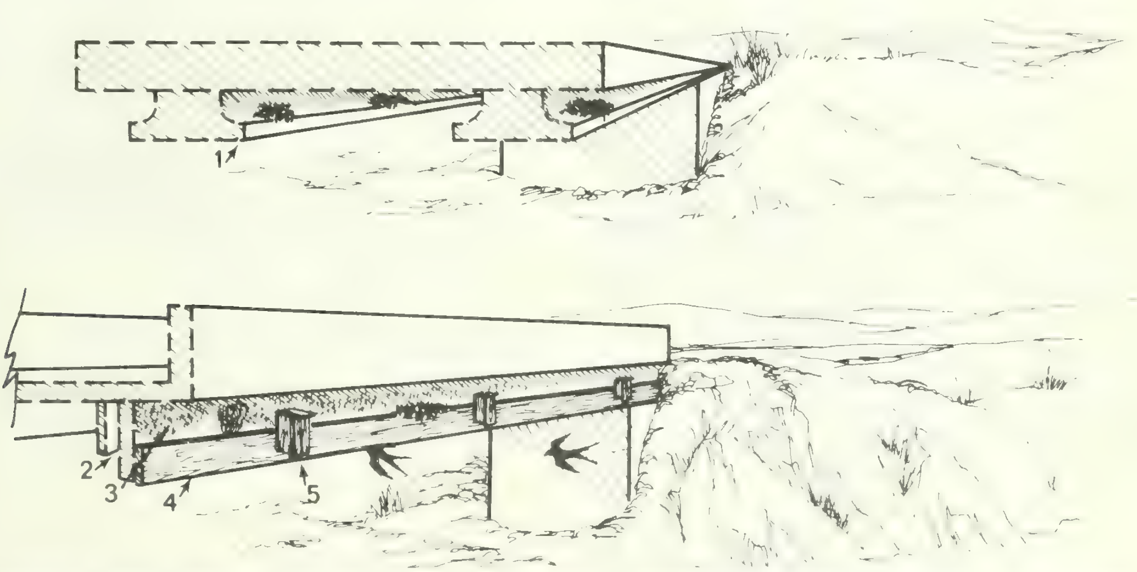

Figure 40.—Concrete bridges can be designed to enhance their potential as wildlife habitat: (1) expanded beams for nest construction, (2) manmade crevice in which bats can roost and rear young, (3) roughened concrete to aid nest construction by some species of birds, (4) wooden plank to create a platform on which birds can nest, and (5) bird boxes to enhance use by a variety of birds.

If a bridge with well-established wildlife use is to be replaced, it may be desirable to construct the new bridge alongside of the old one, retaining the old bridge as wildlife habitat (see fig. 23). The new bridge can be constructed with the above mentioned modifications to increase potential wildlife use. Thus, unusual wildlife habitats can be increased and maintained over time.

ROCK WALLS, ROCK JACKS, ROCK CRIBS, AND SHEEPHERDER MONUMENTS

If rock walls, rock jacks, rock cribs, and sheepherder monuments are to be constructed, wildlife values can be enhanced by using large rocks, 30 to 60 cm (12 to 24 in) in diameter. Wooden posts used in the construction of rock jacks and wooden rock cribs are used as perches by birds—particularly raptors (Marion and Ryder 1975). Rock walls and wire rock cribs, on the other hand, do not usually have wooden posts as part of their structure; but long wooden posts can be wired to a rock crib or placed inside of a crib and held in place with the rocks (fig. 41). Wooden posts can also be wired to steel posts or interspersed with steel posts along a fence, but they should be taller than the steel posts. Further, a wooden crosspiece secured to the top of a wooden post may enhance raptor use (fig. 42).

Figure 41.—Long wooden posts, but shorter than these old telephone poles, can be placed inside wire rock cribs and held in place with the rocks. Such posts can be used as perches by birds—particularly raptors—which will add to a rock crib's value as wildlife habitat. (Chris Maser photograph)

Wildlife use can be augmented by interspersing rock jacks on a fence stabilized primarily by rock cribs and vice versa and by the strategic placement of wooden perching posts. Bird boxes attached to fences can provide additional nesting and roosting places for birds and shelter for small mammals. The tops of these boxes may represent roosting sites for common nighthawks (*Chordeiles minor*) and sunning places for lizards (fig. 43). These structures add cover and form dispersal routes for some species of wildlife.

If a fence is to be removed, therefore, established wildlife-habitat values can be retained over long periods by leaving the rock structures intact.

WOODEN CORRALS AND FENCES WITH WOODEN POSTS

Abandoned wooden corrals, if left intact, will be used by wildlife for years as perches and for shade.

If a fence with wooden posts is to be replaced by an all-steel fence, then some of the wooden posts can be incorporated into the new fence. If a fence is to be removed and not replaced, however, then some of the wooden posts could be left intact. In this way they will continue to provide perches for raptors and other birds and shade for small ground-dwelling animals.

POWERLINES

Particular attention should be given to planning powerline routes that will minimize impacts on critical habitats, especially riparian zones.

Closure and non-maintenance of all possible roads associated with powerlines may contribute to the welfare of wildlife, but this will reduce human-wiidlife contacts. On the other hand, if roads must be open or maintained, then closure to other than official use would be of some value to wildlife.

Figure 42.—Wooden posts can be interspaced along all-steel fences to enhance the habitat for perching birds. In addition, if the wooden posts are taller than the steel posts and have a wooden cross-piece secured to their tops, they may enhance use of the surrounding habitat by raptors.

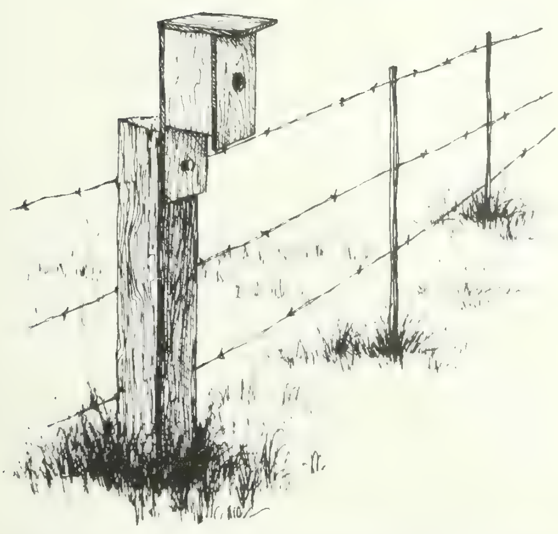

Figure 43.—Bird boxes attached to fences can provide additional nesting and roosting places for birds and shelter for small mammals. The tops of these boxes may represent roosting sites for common nighthawks (*Chordeiles minor*) and sunning places for lizards.

If a right-of-way goes through an extensive area of similar habitat, such as a juniper woodland, it may be advantageous to wildlife if the right-of-way is made wide enough and of such a configuration so as to maximize wildlife diversity and to maintain self-sustaining populations of wildlife within its boundaries (see fig. 37). Conversely, a right-of-way that cannot be diverted around but must go through scarce habitat—habitat that occupies a small percent of the surrounding landscape—should be kept as narrow as possible.

When trees, such as juniper (*Juniperus* spp.), are killed, cut down or chained, leaving some dead, down woody debris will enhance habitat diversity and, therefore, wildlife species diversity (Maser and Gashwiler 1978).

Although all powerlines, poles, and towers should be made safe for birds, when a raptor nests within a tower in a way that a hazard is created, the nest should be moved, intact, to a new locality within the tower if possible and should be securely fastened. This action will remove the hazard and will allow the birds to successfully rear their young (Wayne Elmore, personal communication 1978). In addition, construction of nesting platforms on powerline towers has the potential of increasing raptor nesting habitat and reproductive success.

With careful planning and land-use management, powerline rights-of-way have the potential for creating wildlife habitats in

specific localities. They may be used not only to increase habitat diversity but also to increase the populations of particular species of wildlife.

CROPLANDS

Proposed cropland development within managed rangeland should be evaluated for potential wildlife conflicts prior to its installation. The initial plan should provide a full analysis of those conflicts and how they are to be resolved. Most cropland developments within rangelands will be detrimental to native species because of the extreme alteration in their habitats (fig. 44). And species that will use such habitats are apt to become "pests."

Agricultural activities may provide a niche for exotic species, such as ring-necked pheasants. Their welfare can be enhanced by intentionally creating brush rows between fields, natural areas along irrigation ditches, etc.

Figure 44.—Most cropland developments within rangelands will be detrimental to native species of wildlife because of the extreme alteration in their habitats. As a result, those wildlife species that will use cropland habitats are apt to become "pests." (Bureau of Land Management photograph by M. Hurd)

Summary

Manmade structures, such as homesteads, bridges, and rock walls, blend into the rangelands of the Great Basin with the passage of time. They create habitat diversity in large expanses of otherwise relatively homogeneous landscapes, thereby increasing the diversity of wildlife (fig. 45). And they may be esthetically pleasing.

Figure 45.—Manmade structures, such as homesteads, blend into the rangelands of the Great Basin with the passage of time. In so doing, they create habitat diversity in large expanses of otherwise relatively homogeneous landscapes, thereby increasing the diversity of wildlife. Note: The grassy area immediately above the house is a spring — the homestead's water supply. (Chris Maser photograph)

Manmade structures, when obviously "old" or of a past era, come to be considered as part of our national heritage and by law may be preserved for the reflective consideration and enjoyment of the public. These structures, when considered as habitat, also become part of our natural heritage in that they bring man closer to wildlife.

The importance of manmade structures as habitats for wildlife is just being perceived in land management. And it is possible, with careful planning, to manage such structures simultaneously for the enhancement and perpetuation of their cultural and their wildlife values. In turn, this will provide greater enjoyment for the land owners—the public.

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Appendix 1

Generalized response of terrestrial species of vertebrate wildlife to manmade habitats.

Legend: 0 = generally neutral response
— = generally negative response
+ = generally positive response

Common name	Scientific name	Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
Amphibians							
long-toed salamander	*Ambystoma macrodactylum*	+	0	+	0	0	—
Great Basin spadefoot	*Scaphiopus intermontanus*	+	—	+	0	—	—
western toad	*Bufo boreas*	+	0	+	0	—	—
Woodhouse toad	*Bufo woodhousei*	+	0	+	0	—	—
Pacific tree frog	*Hyla regilla*	+	—	+	0	—	—
spotted frog	*Rana pretiosa*	+	0	0	0	0	0
leopard frog	*Rana pipiens*	+	0	0	0	0	—
bullfrog	*Rana catesbeiana*	+	0	0	0	0	0
Reptiles							
collard lizard	*Crotaphytus collaris*	—	—	—	0	—	—
leopard lizard	*Crotaphytus wislizeni*	—	—	—	+	—	—
western fence lizard	*Sceloporus occidentalis*	0	—	+	—	—	—
sagebrush lizard	*Sceloporus graciosus*	0	0	0	0	—	—
side-blotched lizard	*Uta stansburiana*	—	—	+	0	—	—
desert horned lizard	*Phrynosoma platyrhinos*	0	—	0	0	0	—
short-horned lizard	*Phrynosoma douglassi*	0	—	0	0	0	—
western skink	*Eumeces skiltonianus*	+	—	+	+	—	—
western whiptail	*Cnemidophorus tigris*	+	—	+	+	—	—
rubber boa	*Charina bottae*	+	—	+	+	—	—
yellow-bellied racer	*Coluber constrictor*	+	—	+	+	—	—
striped whipsnake	*Masticophis taeniatus*	+	—	+	+	—	—
gopher snake	*Pituophis melanoleucus*	+	—	+	+	—	—
common garter snake	*Thamnophis sirtalis*	+	—	+	0	—	—
wandering garter snake	*Thamnophis elegans*	+	—	+	0	—	—
western ground snake	*Sonora semiannulata*	+	—	+	0	—	—
night snake	*Hypsiglena torquata*	+	—	+	+	—	—
western rattlesnake	*Crotalus viridis*	+	—	+	+	—	—
Birds							
common loon	*Gavia immer*	—	0	0	0	0	0
red-necked grebe	*Podiceps grisegena*	—	0	0	0	0	0
horned grebe	*Podiceps auritus*	—	0	0	0	0	0

Appendix 1 (continued)

Wildlife species: Common name	Scientific name	Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
eared grebe	*Podiceps nigricollis*	—	0	0	0	0	0
western grebe	*Aechmophorus occidentalis*	—	0	0	0	0	0
pied-billed grebe	*Podilymbus podiceps*	—	0	0	0	0	0
white pelican	*Pelecanus erythrorhynchos*	—	0	0	0	0	—
double-crested cormorant	*Phalacrocorax auritus*	—	0	0	0	0	0
great blue heron	*Ardea herodias*	+	0	0	0	0	—
green heron	*Butorides virescens*	+	0	0	0	0	0
cattle egret	*Bubulcus ibis*	+	0	0	0	0	—
common egret	*Casmerodius albus*	+	0	0	0	0	—
black-crowned night heron	*Nycticorax nycticorax*	+	0	0	0	0	0
American bittern	*Botaurus lentiginosus*	+	0	0	0	0	0
least bittern	*Ixobrychus exilis*	+	0	0	0	0	0
white-faced ibis	*Plegadis chihi*	+	0	0	0	0	0
whistling swan	*Olor columbianus*	+	0	0	0	0	—
Canada goose	*Branta canadensis*	+	0	0	0	0	—
white-fronted goose	*Anser albifrons*	+	0	0	0	0	—
snow goose	*Chen caerulescens*	+	0	0	0	0	—
Ross' goose	*Chen rossii*	+	0	0	0	0	—
mallard	*Anas platyrhynchos*	+	0	0	0	0	—
gadwall	*Anas strepera*	+	0	0	0	0	—
pintail	*Anas acuta*	+	0	0	0	0	—
green-winged teal	*Anas crecca*	+	0	0	0	0	—
blue-winged teal	*Anas discors*	+	0	0	0	0	—
cinnamon teal	*Anas cyanoptera*	+	0	0	0	0	0
American wigeon	*Anas americana*	+	0	0	0	0	—
northern shoveler	*Anas clypeata*	+	0	0	0	0	—
wood duck	*Aix sponsa*	+	0	0	0	0	0
redhead	*Aythya americana*	+	0	0	0	0	0
ring-necked duck	*Aythya collaris*	+	0	0	0	0	—
canvasback	*Aythya valisineria*	+	0	0	0	0	0
greater scaup	*Aythya marila*	+	0	0	0	0	0
lesser scaup	*Aythya affinis*	+	0	0	0	0	0
common goldeneye	*Bucephala clangula*	+	0	0	0	0	0
Barrow's goldeneye	*Bucephala islandica*	+	0	0	0	0	0
bufflehead	*Bucephala albeola*	+	0	0	0	0	0
oldsquaw	*Clangula hyemalis*	+	0	0	0	0	0
King eider	*Somateria spectabilis*	+	0	0	0	0	0
ruddy duck	*Oxyura jamaicensis*	+	0	0	0	0	0
hooded merganser	*Lophodytes cucullatus*	+	0	0	0	0	0

Appendix 1 (continued)

Common name	Scientific name	Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
common merganser	*Mergus merganser*	+	0	0	0	0	0
red-breasted merganser	*Mergus serrator*	+	0	0	0	0	0
turkey vulture	*Cathartes aura*	+	+	+	+	+	—
goshawk	*Accipiter gentilis*	+	0	0	0	0	0
sharp-shinned hawk	*Accipiter striatus*	+	0	0	0	0	0
Cooper's hawk	*Accipiter cooperii*	+	0	0	0	0	0
red-tailed hawk	*Buteo jamaicensis*	+	+	+	+	—	—
Swainson's hawk	*Buteo swainsoni*	+	+	+	+	—	—
rough-legged hawk	*Buteo lagopus*	+	+	+	+	—	—
ferruginous hawk	*Buteo regalis*	+	—	+	+	—	—
golden eagle	*Aquila chrysaetos*	+	+	+	+	—	—
bald eagle	*Haliaeetus leucocephalus*	+	+	+	+	—	—
marsh hawk	*Circus cyaneus*	+	—	+	+	—	—
osprey	*Pandion haliaetus*	+	0	0	0	0	0
prairie falcon	*Falco mexicanus*	+	0	+	+	—	—
peregrine	*Falco peregrinus*	+	0	+	+	—	—
merlin	*Falco columbarius*	+	0	+	+	—	—
American kestrel	*Falco sparverius*	+	0	+	+	—	—
blue grouse	*Dendragapus obscurus*	+	0	+	0	0	—
ruffed grouse	*Bonasa umbellus*	+	0	0	0	0	—
sage grouse	*Centrocercus urophasianus*	+	0	0	0	0	—
California quail	*Lophortyx californicus*	+	0	+	+	—	—
mountain quail	*Oreortyx pictus*	+	0	0	0	—	—
chukar	*Alectoris chukar*	+	0	+	0	0	—
gray partridge	*Perdix perdix*	+	0	0	0	—	—
ring-necked pheasant	*Phasianus colchicus*	+	—	—	0	—	—
sandhill crane	*Grus canadensis*	+	0	0	0	—	—
Virginia rail	*Rallus limicola*	+	0	0	0	0	0
sora	*Porzana carolina*	+	0	0	0	0	0
American coot	*Fulica americana*	+	0	0	0	—	—
snowy plover	*Charadrius alexandrinus*	+	0	0	0	0	—
killdeer	*Charadrius vociferus*	+	0	0	0	0	—
mountain plover	*Charadrius montanus*	+	0	0	0	0	—
common snipe	*Capella gallinago*	+	0	0	0	0	—
long-billed curlew	*Numenius americanus*	—	0	+	0	0	—
semi-palmated plover	*Charadrius semipalmatus*	+	0	0	0	0	—
spotted sandpiper	*Actitis macularia*	+	0	0	0	0	—
solitary sandpiper	*Tringa solitaria*	+	0	0	0	0	—
greater yellowlegs	*Tringa melanoleuca*	+	0	0	0	0	—

Appendix 1 (continued)

Common name	Scientific name	Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
lesser yellowlegs	*Tringa flavipes*	+	0	0	0	0	—
willet	*Catoptrophorus semipalmatus*	+	0	0	0	0	—
pectoral sandpiper	*Calidris melanotos*	+	0	0	0	0	—
Baird's sandpiper	*Calidris bairdii*	+	0	0	0	0	—
least sandpiper	*Calidris minutilla*	+	0	0	0	0	—
western sandpiper	*Calidris mauri*	+	0	0	0	0	—
long-billed dowitcher	*Limnodromus scolopaceus*	+	0	0	0	0	—
marbled godwit	*Limosa fedoa*	+	0	0	0	0	—
American avocet	*Recurvirostra americana*	+	0	0	0	0	—
black-necked stilt	*Himantopus mexicanus*	+	0	0	0	0	—
Wilson's phalarope	*Steganopus tricolor*	+	0	0	0	0	0
northern phalarope	*Lobipes lobatus*	+	0	0	0	0	0
herring gull	*Larus thayeri*	+	0	0	0	0	—
California gull	*Larus californicus*	+	0	0	0	0	—
ring-billed gull	*Larus delawarensis*	+	0	0	0	0	—
Franklin's gull	*Larus pipixcan*	+	0	0	0	0	—
Bonaparte's gull	*Larus philadelphia*	+	0	0	0	0	—
Forster's tern	*Sterna forsteri*	+	0	0	0	0	0
Caspian tern	*Hydroprogne caspia*	+	0	0	0	0	0
black tern	*Chlidonias niger*	+	0	0	0	0	0
rock dove	*Columba livia*	+	+	+	0	0	—
mourning dove	*Zenaida macroura*	+	0	0	0	0	—
yellow-billed cuckoo	*Coccyzus americanus*	+	0	0	0	0	0
barn own	*Tyto alba*	+	—	+	+	0	—
screech owl	*Otus asio*	+	—	+	+	0	—
flammulated owl	*Otus flammeolus*	+	—	+	+	0	—
great horned owl	*Bubo virginianus*	+	—	+	+	+	—
pygmy owl	*Glaucidium gnoma*	+	—	+	+	+	—
burrowing owl	*Athene cunicularia*	+	—	+	+	0	—
long-eared owl	*Asio otus*	+	—	+	+	0	—
short-eared owl	*Asio flammeus*	+	0	+	+	0	—
saw-whet owl	*Aegolius acadicus*	+	0	0	+	0	—
poorwill	*Phalaenoptilus nuttallii*	+	0	+	0	0	—
common nighthawk	*Chordeiles minor*	+	+	+	0	0	—
black swift	*Cypseloides niger*	+	0	+	0	0	—
Vaux's swift	*Chaetura vauxi*	+	0	+	0	0	—
white-throated swift	*Aeronautes saxatalis*	+	0	+	0	0	—
black-chinned hummingbird	*Archilochus alexandri*	+	0	0	0	0	0
Anna's hummingbird	*Calypte anna*	+	0	0	0	0	0

Appendix 1 (continued)

Common name	Scientific name	Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
broad-tailed hummingbird	*Selasphorus platycercus*	+	0	0	0	0	0
rufous hummingbird	*Selasphorus rufus*	+	0	0	0	0	0
calliope hummingbird	*Stellula calliope*	+	0	0	0	0	0
belted kingfisher	*Megaceryle alcyon*	+	—	0	0	0	0
common flicker	*Colaptes auratus*	+	—	0	—	0	0
Lewis' woodpecker	*Asyndesmus lewis*	+	—	0	—	0	0
yellow-bellied sapsucker	*Sphyrapicus varius*	+	0	0	0	0	0
Williamson's sapsucker	*Sphyrapicus thyroideus*	+	0	0	0	0	0
hairy woodpecker	*Dendrocopos villosus*	+	0	0	0	0	0
downy woodpecker	*Dendrocopos pubescens*	+	0	0	0	0	0
white-headed woodpecker	*Dendrocopos albolarvatus*	+	0	0	0	0	0
eastern kingbird	*Tyrannus tyrannus*	+	0	0	0	0	—
western kingbird	*Tyrannus verticalis*	+	—	+	0	0	—
ash-throated flycatcher	*Myiarchus cinerascens*	+	0	+	+	0	—
Say's phoebe	*Sayornis saya*	+	+	+	+	0	0
willow flycatcher	*Empidonax traillii*	+	0	0	0	0	—
Hammond's flycatcher	*Empidonax hammondii*	+	0	0	0	0	—
gray flycatcher	*Empidonax wrightii*	+	+	+	+	0	—
western flycatcher	*Empidonax difficilis*	+	0	0	0	0	—
western wood pewee	*Contopus sordidulus*	+	0	0	0	0	—
olive-sided flycatcher	*Nuttallornis borealis*	+	0	0	0	0	—
horned lark	*Eremphila alpestris*	0	+	+	0	0	—
violet-green swallow	*Tachycineta thalassina*	+	0	0	0	0	—
tree swallow	*Iridoprocne bicolor*	+	0	0	0	0	—
bank swallow	*Riparia riparia*	+	+	0	0	0	—
rough-winged swallow	*Stelgidopteryx ruficollis*	+	+	0	0	0	—
barn swallow	*Hirundo rustica*	+	+	0	0	0	—
cliff swallow	*Petrochelidon pyrrhonota*	+	+	0	0	0	—
gray jay	*Perisoreus canadensis*	+	0	0	0	0	—
Steller's jay	*Cyanocitta stelleri*	+	0	0	0	0	—
scrub jay	*Aphelocoma coerulescens*	+	0	+	0	0	—
black-billed magpie	*Pica pica*	+	+	+	+	0	—
common raven	*Corvus corax*	+	+	+	+	+	—
common crow	*Corvus brachyrhynchos*	+	0	+	0	0	—
pinyon jay	*Gymnorhinus cyanocephalus*	+	0	+	+	0	—
Clark's nutcracker	*Nucifraga columbiana*	+	0	0	0	0	0
black-capped chickadee	*Parus atricapillus*	+	0	0	0	0	0
mountain chickadee	*Parus gambeli*	+	0	0	0	0	0
bushtit	*Psaltriparus minimus*	+	0	0	0	0	0

Appendix 1 (continued)

Wildlife species: Common name	Scientific name	Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
white-breasted nuthatch	*Sitta carolinensis*	+	0	0	0	0	0
red-breasted nuthatch	*Sitta canadensis*	+	0	0	0	0	0
brown creeper	*Certhia familiaris*	+	0	0	0	0	0
dipper	*Cinclus mexicanus*	+	+	0	0	0	0
house wren	*Troglodytes aedon*	+	+	+	0	0	0
winter wren	*Troglodytes troglodytes*	+	+	0	0	0	0
long-billed marsh wren	*Telmatodytes palustris*	+	0	0	0	0	0
canyon wren	*Catherpes mexicanus*	+	+	+	0	0	0
rock wren	*Salpinctes obsoletus*	+	+	+	0	0	0
gray catbird	*Dumetella carolinensis*	+	0	0	0	0	0
brown thrasher	*Toxostoma rufum*	+	0	0	0	0	—
sage thrasher	*Oreoscoptes montanus*	+	0	+	0	0	—
American robin	*Turdus migratorius*	+	0	+	0	0	—
varied thrush	*Ixoreus naevius*	+	0	0	0	0	—
hermit thrush	*Catharus guttatus*	+	0	0	0	0	0
Swainson's thrush	*Catharus ustulatus*	+	0	0	0	0	0
veery	*Catharus fuscescens*	+	0	0	0	0	0
western bluebird	*Sialia mexicana*	+	0	+	+	0	—
mountain bluebird	*Sialia currucoides*	+	0	+	+	0	—
Townsend's solitaire	*Myadestes townsendi*	+	0	+	0	0	0
blue-gray gnatcatcher	*Popioptila caerulea*	+	0	+	0	0	0
water pipit	*Anthus spinoletta*	+	+	+	0	0	—
bohemian waxwing	*Bombycilla garrulus*	+	0	0	0	0	0
cedar waxwing	*Bombycilla cedrorum*	+	0	0	0	0	0
northern shrike	*Lanius excubitor*	+	+	+	+	0	0
loggerhead shrike	*Lanius ludovicianus*	+	+	+	+	0	0
starling	*Sturnus vulgaris*	+	0	0	0	0	+
solitary vireo	*Vireo solitarius*	+	0	0	0	0	0
red-eyed vireo	*Vireo olivaceus*	+	0	0	0	0	0
warbling vireo	*Vireo gilvus*	+	0	0	0	0	0
orange-crowned warbler	*Vermivora celata*	+	0	0	0	0	0
yellow warbler	*Dendroica petechia*	+	0	0	0	0	0
yellow-rumped warbler	*Dendroica coronata*	+	0	0	0	0	0
black-throated gray warbler	*Dendroica nigrescens*	+	0	0	0	0	0
Townsend's warbler	*Dendroica townsendi*	+	0	0	0	0	0
ovenbird	*Seiurus aurocapillus*	+	0	0	0	0	0
MacGillivray's warbler	*Oporornis tolmiei*	+	0	0	0	0	0
common yellowthroat	*Geothlypis trichas*	+	0	0	0	0	0
yellow-breasted chat	*Icteria virens*	+	0	0	0	0	0

Appendix 1 (continued)

Wildlife species: Common name	Scientific name	Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
Wilson's warbler	*Wilsonia pusilla*	+	0	0	0	0	0
American redstart	*Setophaga ruticilla*	+	0	0	0	0	0
house sparrow	*Passer domesticus*	+	+	+	+	0	—
bobolink	*Dolichonyx oryzivorus*	+	0	0	0	0	—
western meadowlark	*Sturnella neglecta*	+	0	+	+	0	—
yellow-headed blackbird	*Xanthocephalus xanthocephalus*	+	0	0	0	0	—
red-winged blackbird	*Agelaius phoeniceus*	+	0	0	0	0	—
northern oriole	*Icterus galbula*	+	0	0	0	0	0
Brewer's blackbird	*Euphagus cyanocephalus*	+	0	0	0	0	—
brown-headed cowbird	*Molothrus ater*	+	0	0	0	0	—
western tanager	*Piranga ludoviciana*	+	0	0	0	0	0
rose-breasted grosbeak	*Pheucticus ludovicianus*	+	0	0	0	0	0
black-headed grosbeak	*Pheucticus melanocephalus*	+	0	0	0	0	0
indigo bunting	*Passerina cyanea*	+	0	0	0	0	0
lazuli bunting	*Passerina amoena*	+	0	0	0	0	0
evening grosbeak	*Hesperiphona vespertina*	+	0	0	0	0	0
purple finch	*Carpodacus purpureus*	+	0	0	0	0	—
Cassin's finch	*Carpodacus cassinii*	+	0	0	0	0	—
house finch	*Carpodacus mexicanus*	+	0	0	0	0	—
common redpol	*Acanthis flammea*	+	0	0	0	0	—
pine siskin	*Spinus pinus*	+	0	0	0	0	—
American goldfinch	*Spinus tristis*	+	0	0	0	0	—
lesser goldfinch	*Spinus psaltria*	+	0	0	0	0	—
green-tailed towhee	*Chlorura chlorura*	+	0	0	0	0	—
rufous-sided towhee	*Pipilo erythrophthalmus*	+	0	0	0	0	—
savannah sparrow	*Passerculus sandwichensis*	+	+	+	0	0	—
grasshopper sparrow	*Ammodramus savannarum*	+	+	+	0	0	—
vesper sparrow	*Pooecetes gramineus*	+	+	+	0	0	—
lark sparrow	*Chondestes grammacus*	+	0	+	0	0	—
sage sparrow	*Amphispiza belli*	+	0	+	0	0	—
dark-eyed junco	*Junco hyemalis*	+	0	0	0	0	—
tree sparrow	*Spizella arborea*	+	0	0	0	0	—
chipping sparrow	*Spizella passerina*	+	0	0	0	0	—
Brewer's sparrow	*Spizella breweri*	+	0	+	0	0	—
white-crowned sparrow	*Zonotrichia leucophrys*	+	0	+	0	0	—
golden-crowned sparrow	*Zonotrichia atricapilla*	+	0	+	0	0	—
fox sparrow	*Passerella iliaca*	+	0	0	0	0	—
Lincoln's sparrow	*Melospiza lincolnii*	+	0	0	0	0	—
song sparrow	*Melospiza melodia*	+	0	0	0	0	—

Appendix 1 (continued)

Common name	Scientific name	Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
Lapland longspur	*Calcarius lapponicus*	+	0	+	0	0	—
snow bunting	*Plectrophenax nivalis*	+	0	+	0	0	—
Mammals							
Malheur shrew	*Sorex preblei*	+	—	0	0	—	—
wandering shrew	*Sorex vagrans*	+	—	+	+	—	—
Merriam shrew	*Sorex merriami*	+	—	+	+	—	—
little brown myotis	*Myotis lucifugus*	+	+	0	0	0	0
Yuma myotis	*Myotis yumanensis*	+	+	0	0	0	0
long-eared myotis	*Myotis evotis*	+	+	0	0	0	0
fringed myotis	*Myotis thysanodes*	+	+	0	0	0	0
long-legged myotis	*Myotis volans*	+	+	0	0	0	0
California myotis	*Myotis californicus*	+	+	0	0	0	0
small-footed myotis	*Myotis leibi*	+	+	0	0	0	0
silver-haired bat	*Lasionycteris noctivagans*	+	+	0	0	0	0
western pipistrelle	*Pipistrellus hesperus*	+	+	0	0	0	0
big brown bat	*Eptesicus fuscus*	+	+	0	0	0	0
hoary bat	*Lasiurus cinereus*	+	0	0	0	0	—
spotted bat	*Euderma maculata*	0	0	0	0	0	—
western big-eared bat	*Plecotus townsendi*	+	+	0	0	0	0
pallid bat	*Antrozous pallidus*	+	+	0	0	0	0
pygmy rabbit	*Sylvilagus idahoensis*	+	—	+	+	—	—
mountain cottontail	*Sylvilagus nuttalli*	+	—	+	+	—	—
white-tailed jackrabbit	*Lepus townsendi*	+	—	0	0	—	—
black-tailed jackrabbit	*Lepus californicus*	+	—	0	0	—	—
least chipmunk	*Eutamias minimus*	+	—	+	+	—	—
yellow-pine chipmunk	*Eutamias amoenus*	+	—	+	+	0	—
yellow-bellied marmot	*Marmota flaviventris*	+	—	+	+	0	—
antelope ground squirrel	*Ammospermophilus leucurus*	0	—	0	0	—	—
Townsend ground squirrel	*Spermophilus townsendi*	+	—	+	+	—	—
Richardson ground squirrel	*Spermophilus richardsoni*	+	—	+	+	—	—
Belding ground squirrel	*Spermophilus beldingi*	+	—	+	+	—	—
mantled ground squirrel	*Spermophilus lateralis*	+	+	+	+	0	0
Townsend pocket gopher	*Thomomys townsendi*	+	+	0	0	+	—
northern pocket gopher	*Thomomys talpoides*	+	+	0	0	+	—
little pocket mouse	*Perognathus longimembris*	0	—	0	0	—	—
Great Basin pocket mouse	*Perognathus parvus*	+	—	0	0	+	—
dark kangaroo mouse	*Microdipodops megacephalus*	0	—	0	0	—	—
Ord kangaroo rat	*Dipodomys ordi*	+	+	0	0	0	—

Appendix 1 (continued)

Wildlife species		Abandoned homesteads	Roads and bridges	Rock walls, jacks, cribs, and monuments	Wood corrals and fences	Powerlines	Croplands
Common name	**Scientific name**						
chisel-toothed kangaroo rat	*Dipodomys microps*	+	+	0	0	0	—
beaver	*Castor canadensis*	—	—	0	0	—	—
western harvest mouse	*Reithrodontomys megalotis*	+	—	+	0	+	—
canyon mouse	*Peromyscus crinitus*	0	0	+	0	—	—
deer mouse	*Peromyscus maniculatus*	+	—	+	+	0	—
northern grasshopper mouse	*Onychomys leucogaster*	+	—	0	0	—	—
desert woodrat	*Neotoma lepida*	+	—	+	+	0	—
bushy-tailed woodrat	*Neotoma cinerea*	+	—	+	+	0	—
montane vole	*Microtus montanus*	+	—	0	0	+	—
long-tailed vole	*Microtus longicaudus*	+	—	0	0	+	—
sage vole	*Lagurus curtatus*	0	+	+	0	—	—
muskrat	*Ondatra zibethicus*	—	0	0	0	0	—
western jumping mouse	*Zapus princeps*	+	—	0	0	—	—
porcupine	*Erethizon dorsatum*	+	—	—	0	—	—
coyote	*Canis latrans*	+	—	—	0	—	—
red fox	*Vulpes vulpes*	+	—	+	+	+	—
kit fox	*Vulpes macrotis*	+	—	+	+	+	—
raccoon	*Procyon lotor*	+	—	+	+	—	—
long-tailed weasel	*Mustela frenata*	+	—	+	+	—	—
mink	*Mustela vison*	+	—	+	0	—	—
badger	*Taxidea taxus*	+	—	+	+	+	—
spotted skunk	*Spilogale putorius*	+	—	+	+	—	—
striped skunk	*Mephitis mephitis*	+	—	+	+	—	—
river otter	*Lutra canadensis*	0	—	0	0	—	—
cougar	*Felis concolor*	+	—	0	0	—	—
bobcat	*Lynx rufus*	+	—	—	0	—	—
mule deer	*Odocoileus hemionus*	+	—	—	—	—	—
pronghorn	*Antilocapra americana*	—	—	—	—	—	—
bighorn sheep	*Ovis canadensis*	—	—	—	—	—	—

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife — if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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GENERAL TECHNICAL REPORT
PNW-87
JUNE 1979

OMPARATIVE AUTECOLOGICAL HARACTERISTICS OF NORTHWESTERN TREE PECIES--- A LITERATURE REVIEW

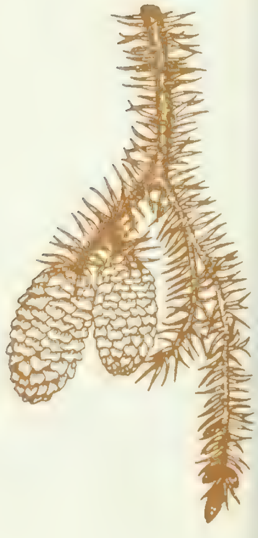
BY DON MINORE

ABSTRACT

This report is a compilation of autecological information previously scattered about in several hundred publications It includes a comparison of the tolerances, traits, and attributes of native northwestern tree species. The species are ranked with respect to 69 environmental factors, phenotypic characteristics, and physical parameters. These rankings, with the literature references from which they were derived, should be useful aids to species selection, management, and research in the Pacific Northwest.

KEYWORDS: Autecology (plant), native plants, Pacific Northwest.

CONTENTS



INTRODUCTION

More than 40 native tree species are found in the Pacific Northwest[1] (table 1). Often differing almost as much as do the wide range of environments in which they occur, these species comprise an immensely valuable reservoir of growth traits, physiological tolerances, and physical attributes. By carefully selecting the proper species or combinations of species, foresters and forest researchers can often select biological raw material to fit their management and research needs.

Unfortunately, it is difficult to select biological raw material if one does not have some way of comparing this material in terms of the needs to be filled. Much is known about northwestern tree species, but most of this knowledge is scattered about in numerous publications that often are unavailable or unknown to the foresters and researchers who need them. This report is a collection of such scattered knowledge gleaned from available publications.

Published autecological information was included here whenever references contained comparisons or two or more northwestern tree species. Conclusions obtained by comparing the absolute values resulting from separate observations and experiments have been avoided. As Jarvis (1963) wrote, "The conditions of experiments are never the same as those occurring naturally, so that difficulties arise in applying the results to explain situations observed in the field. However, by doing similar experiments with several species under similar conditions, physiological differences in response between species may be found and these differences may be of ecological significance."

Differences, not absolute values, are presented in this report. Species responses to differing conditions are complex and difficult to compare, however, even when only relative differences between species are investigated. Four major problems are involved: (1) Genetic variation within the species being compared may be almost as great as the variation among species, and differing ecotypic responses may obscure species comparisons; (2) Responses to differences in one condition may be confounded by responses to differences in other, associated conditions; (3) Species occupying widely diverse environments are difficult to compare directly, and young seedlings often must be grown under artificial conditions if these species are to be compared; (4) Young seedlings and older trees do not always respond similarly, and conclusions based upon seedling growth may not be valid for more mature trees. These problems are well summarized by Krajina (1955) and Spurr (1964, p. 165).

Nevertheless, northwestern tree species have been compared by many different investigators in many different environments. If carefully evaluated, these comparisons should be useful aids in selecting species for various environmental conditions. When all of them are listed, the published comparisons should also be useful indicators of unknown relationships and research needs.

Although all of the comparisons cited here involve species listed in table 1, some of these comparisons did not occur in British Columbia, Washington, Oregon, or Idaho. They were all useful, however, and comparisons that occurred elsewhere were not rejected when species characteristics were evaluated.

[1] British Columbia, Washington, Oregon, and Idaho.

Table 1--Northwestern tree species, with their scientific and common names[1]

Scientific name	Common name
Abies amabilis (Dougl.) Forbes	Pacific silver fir
Abies concolor (Gord. and Glend.) Lindl.	White fir
Abies grandis (Dougl.) Lindl.	Grand fir
Abies lasiocarpa (Hook.) Nutt.	Subalpine fir
Abies magnifica A. Murr.	California red fir
Abies magnifica var. *shastensis* Lemm.	Shasta red fir
Abies procera Rehder	Noble fir
Acer macrophyllum Pursh	Bigleaf maple
Acer negundo L.	Boxelder
Alnus rubra Bong.	Red alder
Arbutus menziesii Pursh	Pacific madrone
Betula papyrifera Marsh.	Paper birch
Castanopsis chrysophylla (Dougl.) A.DC.	Golden chinkapin
Chamaecyparis lawsoniana Parl.	Port-Orford-cedar
Chamaecyparis nootkantensis (D. Don) Spach	Alaska-cedar
Fraxinus latifolia Benth.	Oregon ash
Juniperus occidentalis Hook.	Western juniper
Juniperus scopulorum Sarg.	Rocky mountain juniper
Larix laricina (Du Roi) K. Koch	Tamarack
Larix lyalli Parl.	Subalpine larch
Larix occidentalis Nutt.	Western larch
Libocedrus decurrens Torr.	Incense-cedar
Lithocarpus densiflora (H. and A.) Rehd.	Tanoak
Picea breweriana Wats.	Brewer spruce
Picea engelmannii Parry ex Engelm.	Engelmann spruce
Picea glauca (Moench) Voss	White spruce
Picea mariana (Mill.) B.S.P.	Black spruce
Picea sitchensis (Bong.) Carr.	Sitka spruce
Pinus albicaulis Engelm.	Whitebark pine
Pinus attenuata Lemm.	Knobcone pine
Pinus contorta Dougl. ex Loud.	Lodgepole pine
Pinus flexilis James	Limber pine
Pinus jeffreyi Grev. and Balf.	Jeffrey pine
Pinus lambertiana Dougl.	Sugar pine
Pinus monticola Dougl. ex D. Don	Western white pine
Pinus ponderosa Dougl. ex Loud.	Ponderosa pine
Populus balsamifera L.	Balsam poplar
Populus tremuloides Michx.	Quaking aspen
Populus trichocarpa T. and G. ex Hook.	Black cottonwood
Pseudotsuga menziesii (Mirbel) Franco	Douglas-fir
Quercus chrysolepis Liebm.	Canyon live oak
Quercus garryana Dougl.	Oregon white oak
Quercus kelloggii Newb.	California black oak
Sequoia sempervirens (D. Don) Endl.	Redwood
Taxus brevifolia Nutt.	Pacific yew
Thuja plicata Donn	Western redcedar
Tsuga heterophylla (Raf.) Sarg.	Western hemlock
Tsuga mertensiana (Bong.) Carr.	Mountain hemlock
Umbellularia californica (H. and A.) Nutt.	California-laurel

[1] Nomenclature is according to Garrison et al. (1976) and Little (1953). For the sake of clarity, scientific names are used throughout this report.

LIGHT

SHADE TOLERANCE

Shade tolerance will be used here in the restricted sense advocated by Shirley (1943), who defined it as "...the capacity of a tree species to survive in light of low intensity." Proceeding from shade tolerant to intolerant, species are discussed below and ranked in table 2.

Krajina (1965) listed *Abies amabilis* as the most tolerant coniferous tree species in the Pacific Northwest at low elevations and placed it in the same highly tolerant category as *Tsuga mertensiana* and *Chamaecyparis nootkatensis* at subalpine altitudes. Franklin (1964) considered *A. amabilis* to be even more tolerant than *T. mertensiana* in the Washington Cascade Range, also finding it to be more tolerant than *Tsuga heterophylla* in most true fir - hemlock forests. In coastal British Columbia, Schmidt (1957) found *A. amabilis* to at least equal *T. heterophylla* and *Thuja plicata* in shade tolerance, probably being the most tolerant of all native coastal conifers. This ranking is supported by Hanzlik (1932), who noted that *A. amabilis* is more tolerant than *Tsuga heterophylla* on the western and southern slopes of the Olympic Mountains. It conflicts with the observations of Buckland et al. (1949), who noted that *A. amabilis* appeared to be less tolerant than *T. heterophylla* on Vancouver Island. Working with the collected observations of others on a national scale, without the local experience of the authorities cited above, Sudworth (1908) and Baker (1949) ranked *Abies amabilis* as less shade tolerant than *Taxus brevifolia*, *Thuja plicata*, *Chamaecyparis nootkatensis*, and *Tsuga heterophylla*. Their rankings probably are less accurate than those of Schmidt (1957), Franklin (1964), and Krajina (1965).

The above statements were based upon field observations of seral and climax stands as they existed in nature, where shade tolerance was assumed to have been the dominant

Table 2--Comparative shade tolerance of northwestern tree species[1/]

Abies amabilis, *Tsuga heterophylla*, *Taxus brevifolia*
Thuja plicata, *Chamaecyparis nootkatensis*, *Tsuga mertensiana*
Abies lasiocarpa
Abies grandis
Picea sitchensis
Picea glauca
Abies concolor, *Picea breweriana*
Abies magnifica var. *shastensis*
Chamaecyparis lawsoniana
Pinus monticola
Pseudotsuga menziesii
Pinus lambertiana
Libocedrus decurrens, *Abies procera*, *Picea engelmannii*, *Alnus rubra*
Pinus contorta
Larix occidentalis
Pinus ponderosa
Juniperus occidentalis, *Quercus kelloggii*

[1/] Compiled from information published by Larsen (1930), Haig et al. (1941), Baker (1949), Buckland et al. (1949), Wood (1955), Edwards (1957), Schmidt (1957), Tackle (1959), Franklin (1964), Franklin and Mitchell (1967), Hodges and Scott (1968), Krajina (1965, 1970), Krueger and Ruth (1969), Thornburgh (1969), Eis (1970), Tinus (1970), Brix (1972), Emmingham and Waring (1973), Franklin and Dyrness (1973), Wali and Krajina (1973), Ronco (1975), Edmonds (1975), Waring et al. (1975). More shade tolerant species are listed above less tolerant ones. Species on the same line are not necessarily equal, but data are insufficient for their separation.

factor determining species relationships. Other factors may have been involved, however, and successional status cannot always be equated with relative shade tolerance. When he measured seedlings growing under low-light conditions, Thornburgh (1969) found *Tsuga heterophylla* photosynthesis and height growth rates to be higher than those of *Abies amabilis*. When all field and laboratory observations are considered, it is difficult to compare the shade tolerances of *Abies amabilis*, *Tsuga heterophylla*, and *Taxus brevifolia*. Nevertheless, these three species are the most shade-tolerant trees in the Pacific Northwest.

Tsuga mertensiana is slightly less tolerant than *Abies amabilis* in British Columbia (Krajina 1970). Larsen (1930) also rated it as slightly less tolerant than *Thuja plicata* and *Taxus brevifolia* in Montana and northern Idaho--a rating supported by Baker's nationwide poll of professional opinion in 1949. *Tsuga mertensiana* is the most tolerant species present at high elevations in most of southern Oregon (Franklin 1964), but it may be less shade tolerant than *Abies concolor* or *Picea breweriana* in the Siskiyou Mountains (Waring et al. 1975).

Although Sudworth (1908) noted that *Chamaecyparis nootkatensis* is less shade tolerant than *Thuja plicata*, Krajina (1965, 1970) considered it to be slightly more tolerant. Both species probably are about as shade tolerant as *Tsuga mertensiana* in most environments. Referring to studies of seedling mortality, Harris and Farr (1974) concluded that *Thuja plicata* is less shade tolerant than *Tsuga heterophylla* or *Picea sitchensis* in southeastern Alaska. Their seedling mortality may not have been a result of shade intolerance, but *T. plicata* seems to be less tolerant in coastal Alaska than it is inland or farther south. Larsen (1930) and Haig et al. (1941) rated *T. plicata* as even more shade tolerant than *Tsuga heterophylla* in the Rocky Mountains.

Abies lasiocarpa is less tolerant than *A. amabilis* or *Tsuga mertensiana* (Franklin and Mitchell 1967). Despite the contrary opinions of Sudworth (1908) and Haig et al. (194 *Abies lasiocarpa* seems to be considerably more shade tolerant than *Picea engelmannii* (Larsen 1930, Baker 1949, LeBarron and Jemison 1953, Smith and Clark 1960, Krajina 1965). *Abies lasiocarpa* also is more shade tolerant than *Picea glau* *Pinus contorta* (Wali and Krajina 19 or *Abies grandis* (Larsen 1930, Bake 1949, Schmidt 1957).

Abies grandis seems to be more shade tolerant than *Pseudotsuga menziesii*, *Pinus monticola*, or *Pice engelmannii* (Sudworth 1908, Larsen 1930, Haig et al. 1941, and Baker 1949). Photosynthetic rates measured by Hodges and Scott (1968) als indicate that it is more shade tolerant than *Abies procera* or *Pice sitchensis*.

Picea sitchensis is more shade tolerant than *Pseudotsuga menziesii* in its native habitat (Wood 1955). *P. sitchensis* also is more shade tolerant than *P. glauca* when grown in controlled environments (Brix 1972).

Although Baker's (1949) poll and Franklin and Dyrness' (1973) tolera table placed *Picea sitchensis*, *Abie grandis*, and *A. concolor* in the sam "tolerant" category, Krajina's (196 ranking of *A. concolor* as considerably less tolerant than the other two species probably is correct. *A. concolor* is shade tolerant, however, for Emmingham and Waring (197 found both *A. concolor* and *A. magni* var. *shastensis* at low-light levels where *Pseudotsuga menziesii* was absent in southwest Oregon. Waring et al. (1975) also found the *Abies* species to be more tolerant than *P. menziesii* and observed that *A. concolor* and *Picea breweriana* are slightly more shade tolerant than *A. magnifica* var. *shastensis*.

Abies magnifica var. *shastensis* is more shade tolerant than *Pinus lambertiana* and *P. monticola* (Kraji 1965, Waring et al. 1975). *Pinus lambertiana*, *P. monticola*, and *Pseudotsuga menziesii* are all given an intermediate tolerance rating by Baker (1949) and Waring et al. (1975); but Krajina (1965) ranked *P. lambertiana* as less tolerant than *Pseudotsuga menziesii*, *P. monticola* as more tolerant. Krajina's ranking seems more appropriate for environments in which these species occur together.

Chamaecyparis lawsoniana is even more shade tolerant than *Pinus monticola*; and it also ranks above *Pseudotsuga menziesii*, *Pinus lambertiana*, *P. contorta*, *Libocedrus decurrens*, *Abies procera*, *Picea engelmannii*, *Alnus rubra*, and *Larix occidentalis* (Baker 1949, James and Hayes 1954, Franklin and Dyrness 1973). Franklin and Dyrness (1973) place it in the same tolerant category as *Lithocarpus densiflora*, *Acer macrophyllum*, and *Sequoia sempervirens*. Zobel and Hawk[2] found *C. lawsoniana*, *Tsuga heterophylla*, and *Pinus monticola* in the same shady microhabitats.

Hodges and Scott (1968) found that the photosynthetic rate of *Abies procera* was less than that of *Pseudotsuga mensiesii* in low-light conditions, greater than *P. menziesii* in high light. These data support the relative tolerance ratings of Baker (1949), who characterized *P. menziesii* as "intermediate," *A. procera* as "intolerant." They apparently conflict with Krajina's (1970) listing of both *A. magnifica* var. *shastensis* and *A. procera* as more shade tolerant than *P. menziesii*. Interacting light and moisture effects may be responsible for conflicts such as this. Atzet and Waring (1970) found that the minimum light requirement for *P. menziesii* increased where moisture became limiting.

Although Baker (1949) and Franklin and Dyrness (1973) listed *Picea engelmannii* as more tolerant than either *Pseudotsuga menziesii* or *Abies procera*, Tinus' (1970) measurements indicate that *P. englemannii* and *Alnus rubra* probably are less shade tolerant than *P. menziesii*. Where subjective ratings conflict with objective measurements, the measurements have been given precedence here. Tinus' results were used in constructing table 2.

Edmonds (1975), describing the photosynthesis measurements of Helms and Rutter, rated *Libocedrus decurrens* as less tolerant than *Pseudotsuga menziesii*, more tolerant than *Pinus ponderosa*. Again, these measurements conflict with the estimated *Pseudotsuga* - *Libocedrus* ratings compiled by Baker (1949), Krajina (1965), and Franklin and Dyrness (1973); but photosynthetic measurements probably are more reliable than estimates of relative tolerance.

Tinus (1970) and Ronco (1975) measured lower light saturation points for [illegible]*icea engelmannii* than for *Pinus con-*[illegible]. These measured indications of greater *P. engelmannii* shade tolerances are supported by the conclusions of several observers (Larsen 1930, Haig et al. 1941, Baker 1949, Krajina 1965, and Franklin and Dyrness 1973). The *Pinus contorta* - *Pinus ponderosa* tolerance difference is less distinctive, but *P. contorta* is more shade tolerant than *P. ponderosa* (Larsen 1930, Krajina 1965, Kerr 1913, and Haig et al. 1941).

Although Mosher (1965) implied that *Larix occidentalis* was more shade tolerant than *Pinus contorta* in a northeastern Washington stand, both Baker (1949) and Tackle (1959) considered *L. occidentalis* to be less tolerant. The shade tolerance of *L. occidentalis* has most often been placed somewhere between the tolerances of *Pinus contorta* and *P. ponderosa* (Larsen 1930, Haig et al. 1941, Krajina 1965).

Larsen (1930) and Krajina (1965) considered *Juniperus occidentalis* to be even less shade tolerant than *Pinus ponderosa*. Edwards (1957) also found *Quercus kelloggii* to be less tolerant than *P. ponderosa*. Krajina (1965) listed *Larix lyalli* and *Pinus albicaulis* as the most intolerant subalpine species.

LIGHT INTENSITY

Many species comparisons in the literature provide supplementary light data in addition to shade tolerance information. Emmingham and Waring (1973) recorded maximum leader growth of *Pseudotsuga menziesii*, *Abies concolor*, and *A. magnifica* var. *shastensis* at 100-percent light intensity in southwestern Oregon. Fairbairn and Neustein (1970) noted a similar response for *Picea sitchensis* grown under full sunlight in England but found that *Pseudotsuga menziesii*, *Abies grandis*, and *Tsuga heterophylla* attained maximum height growth at lower light levels. The English environment may have been responsible for this difference.

Controlled environments were utilized by Tinus (1970) in comparing the photosynthesis of several species under increasing light intensities.

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[2] Zobel, Donald B., and Glenn M. Hawk. The environment of *Chamaecyparis lawsoniana*. Unpublished manuscript.

He found that *Picea sitchensis*, *Tsuga heterophylla*, and *Pseudotsuga menziesii* were light saturated at lower light intensities than *Picea engelmannii* and *Alnus rubra*. Krueger and Ruth (1969) found that *Alnus rubra*'s photosynthetic rate also was higher than those of *Picea sitchensis*, *Tsuga heterophylla*, and *Pseudotsuga menziesii* at high light intensitities. Clark and Lister (1975) measured three times as much chlorophyll per unit fresh weight in *Alnus rubra* as in *P. menziesii* or *Picea sitchensis* and found *A. rubra* photosynthesis to be more efficient in blue light. The *Alnus rubra* seedling certainly seems to be a marvelously effective photosynthetic mechanism.

Hellmers (1964) measured growth distribution effects in *Sequoia sempervirens* and *Abies magnifica* seedlings grown under different light intensities. Although light intensity scarcely affected growth distribution in *S. sempervirens*, high light intensities produced the greatest basal growth in *A. magnifica*.

When Pharis et al. (1967) made diurnal comparisons of *Pseudotsuga menziesii* and *Pinus ponderosa*, they found that *P. menziesii* photosynthetic rates changed more rapidly than those of *P. ponderosa*, increasing faster in the morning and declining sooner and further in the afternoon.

PHOTOPERIOD

Owston's 1974 observations of the effects of shortened photoperiod indicate that *Picea sitchensis* and coastal *Pseudotsuga menziesii* are more sensitive than *Abies procera* and *Pinus ponderosa* to shortened photoperiods. *Picea sitchensis* seems to have a longer optimum photoperiod than *Thuja plicata* (Malcolm and Caldwell 1971). When Vaartaja (1959) used the ratio of height growth under very long days to height growth under very short days in species comparisons, he found *Picea engelmannii* ≥ *P. sitchensis* ≥ *Pinus contorta* ≥ *P. ponderosa* ≥ *Pseudotsuga menziesii* ≥ *Thuja plicata* ≥ *Tsuga mertensiana*. In general, the more northerly a species, the greater was its photoperiodic sensitivity.

TEMPERATURE

Genetic variation within species often makes the comparison of species temperature responses difficult. Different geographic races of the same species differ--sometimes in unexpected ways. For example, northern races and those from inland locations usually are more frost tolerant than their southern and coastal relatives (Haller 1961) Sakai and Okada 1971, Sakai and Weiser 1973). Nevertheless, Conkle et al. (1967) observed more winter injury in *Abies concolor* seedlings from northern locations than in those from southern seed sources. Within-species variation should be kept in mind when pondering the species comparisons presented here. Species temperature responses are considered under three categories: frost tolerance, heat tolerance, and mean temperature conditions.

FROST TOLERANCE

Frost tolerance comparisons are most abundant in the literature. They are summarized in table 3.

The freezing resistances of dormant buds and twigs measured by Sakai and Weiser (1973) show that *Pinus contorta* and *Pinus monticola* are the most frost-resistant northwestern tree species while in the dormant state. Their data indicate *Picea engelmannii* to be the next most resistant, followed by *Populus trichocarpa*, *Alnus rubra*, *Abies lasiocarpa* and *A. concolor*, *Larix occidentalis*, *Pinus ponderosa*, *P. jeffreyi*, *Picea sitchensis*, *Chamaecyparis nootkatensis*, *Thuja plicata* and *Abies grandis*, *A. amabilis*, *Pseudotsuga menziesii*, *Tsuga mertenziana*, and *T. heterophylla*...in approximately that order. This frost resistance ranking, derived from the comparison of frost damage to dormant twigs artificially hardened before freezing in the laboratory, somewhat resembles the less complete but more realistic ranking that can be created by compiling literature references to frost damage in actively growing trees.

Table 3--Comparative frost tolerances of northwestern tree species[1]

Pinus contorta, P. monticola
[illegible]
Populus trichocarpa
Pinus ponderosa, P. jeffreyi, Abies magnifica var. *shastensis, Tsuga mertensiana*
Libocedrus decurrens, Picea breweriana
Pinus lambertiana
Abies concolor, A. lasiocarpa
Abies grandis, A. amabilis
Picea sitchensis
Pseudotsuga menziesii
Thuja plicata
Tsuga heterophylla
Arbutus menziesii

[1] Compiled from information published by Day (1928), Schubert (1955), Duffield (1956), Daubenmire (1957), Wagener (1960), Haller (1961), Stein (1963), Fowells and Stark (1965), Krajina (1970), Cochran and Berntsen (1973), Sakai and Weiser (1973), Waring et al. (1975), and Timmis (undated). Tolerant species are listed above intolerant ones. Species in the same group are not necessarily equal, but data are insufficient for their separation.

Young *Pinus contorta* seedlings are more frost tolerant than young *P. ponderosa* seedlings (Berntsen 1967, Cochran and Berntsen 1973), and a late spring frost in central Oregon damaged *P. contorta* megasporangiate strobili much less than *P. ponderosa* strobili at the same stage of development (Sorensen and Miles 1974).

Pinus jeffreyi may be slightly more frost tolerant than *P. ponderosa* near the California coast (Haller 1959, 1961), but the two species appear equally frost tolerant elsewhere (Wagener 1960, Haller 1961). Frost tolerances of *Abies magnifica* var. *shastensis* and *Tsuga mertensiana* equal that of *P. jeffreyi* (Waring et al. 1975).

Waring et al. noted that *Picea breweriana* is less tolerant of cold temperatures than *Pinus jeffreyi*, more tolerant than *Abies grandis*, *Pseudotsuga menziesii*, or *Pinus jeffreyi*. As *Libocedrus decurrens* is less frost tolerant than *Pinus ponderosa* but more tolerant than *Abies grandis*, *Pseudotsuga menziesii*, or *Pinus lambertiana* (Stein 1963, Fowells and Stark 1965), it may be ranked with *Picea breweriana* in this respect.

Schubert (1955) observed that *Pinus lambertiana* was more susceptible to freezing than *P. ponderosa* and *P. jeffreyi*. *P. lambertiana* survival also was poorer than *Libocedrus decurrens* survival, but better than that of *Abies concolor* in the frost mortality measurements made by Fowells and Stark (1965) in California. Stein's (1963) southwestern Oregon observations were similar--frost damage to *Pinus lambertiana* was more severe than to *Libocedrus decurrens*, but less severe than that to *Abies grandis* or *Pseudotsuga menziesii*. *P. menziesii* is less frost tolerant than *Picea glauca* in the interior of British Columbia (Cayford and Bickerstaff 1968).

A November 1955 cold wave in western Washington damaged the *Abies* spp. less than *Picea sitchensis*, and *P. sitchensis* was less damaged than *Pseudotsuga menziesii* (Duffield 1956). Day (1928) also found *Picea sitchensis* to be more frost resistant than *Pseudotsuga menziesii* in England. Sakai and Okada (1971) found the dormant frost resistance of *Picea sitchensis* to be similar to that of *Chamaecyparis lawsoniana*, but Duffield (1956) observed more damage to *C. lawsoniana*

than to *P. sitchensis* after the November freeze. Similarly, the excellent dormant frost tolerance of *Alnus rubra* reported by Sakai and Weiser (1973) was not evident in November, 1955, when *Alnus* and *Arbutus* trees were extensively killed by unusually cold temperatures (Daubenmire 1957). As Sakai and Weiser measured only the frost tolerance of detached dormant twigs, Duffield's and Daubenmire's observations of entire trees probably are more pertinent. Both Duffield (1956) and Daubenmire (1957) found *Pseudotsuga menziesii* more frost tolerant than *Thuja plicata*, and *T. plicata* more tolerant than *Tsuga heterophylla*. These observations apply only to the shoots, however, for Van Eerden (1974) found *Pseudotsuga* roots to be more susceptible to low temperatures than *Tsuga* roots. *Arbutus menziesii* is "...the least frost resistant tree native to Canada" (Krajina 1970).

HEAT TOLERANCE

Levitt (1951) stated that frost, heat, and drought resistances are basically similar, with resistance to one accompanied by resistance to the other two factors. Although this seems to be true in a general sense, relative resistances to heat injury are not the same as resistances to frost injury when species rankings from the literature are compiled and compared. Unfortunately, only a few species have been compared for heat tolerance.

Pinus lambertiana is more heat resistant than *P. ponderosa* or *Pseudotsuga menziesii* (Cochran 1963). The heat tolerance of *Pinus jeffreyi* is at least equal to that of *P. ponderosa* (Haller 1959), but no *P. jeffreyi* - *P. lambertiana* comparisons are available. *Pseudotsuga menziesii*, *Pinus monticola*, and *Larix occidentalis* seedlings are more heat resistant than *Tsuga heterophylla* or *Thuja plicata* seedlings (Haig 1936). *Pseudotsuga* seedlings also are more resistant than those of *Abies grandis* (Baker 1929), which is more susceptible to heat killing than other species (Schubert and Adams 1971). *Abies lasiocarpa* is able to establish itself in hotter conditions than *Picea engelmannii* - *P. glauca* hybrids in the Rocky Mountains (Day 1964).

MEAN TEMPERATURE CONDITIONS

In addition to comparing frost and heat responses, it often is advantageous to compare species responses to mean temperatures. This may be done by comparing the published relative occurrence and/or growth of species observed under identical temperatures...for several different temperature conditions.

Quercus kelloggii, *Quercus garryana*, and *Arbutus menziesii* occur in the warmest northwestern environments (Cleary and Waring 1969, Zobel et al. 1976). In the eastern Siskiyou Mountains of southern Oregon, *Pinus ponderosa* also often occurs in hot environments (Waring 1969).

Frost tolerance notwithstanding, *Pinus contorta* does not seem to grow any better than *P. ponderosa* under low night temperatures (Cochran 1972). Its boreal range extends farther north, however, than that of *P. ponderosa* (Harlow and Harrar 1950). Although it demands a lower average temperature than *P. ponderosa* and *Pseudotsuga menziesii* in the Rocky Mountains, *Pinus contorta* probably requires a higher temperature than *Picea engelmannii* or *Abies lasiocarpa* (Tackle 1959). Kaufmann and Eckard (1977) recently suggested that *Picea engelmannii* establishment may occur more rapidly than that of *Pinus contorta* in cool environments.

In the central Oregon Cascades *Pseudotsuga menziesii*, *Pinus lambertiana*, *Acer macrophyllum*, and *Libocedrus decurrens* are most important where environments are slightly cooler than those typical of *Arbutus*'s center of importance (Zobel et al. 1976). In controlled environments, *Pseudotsuga menziesii* grows less well than *Pinus ponderosa* under high temperature conditions (see Steinbrenner and Rediske 1964, Pharis et al. 1967). Nevertheless, high temperatures seem to be less detrimental to *P. menziesii* than they are to *Tsuga heterophylla* (Brix 1971). A

small diurnal temperature variation appears to be beneficial for *P. menziesii*, but variation is not required for *Sequoia sempervirens* (Hellmers and Sundahl 1959).

When Oregon Cascade environments cooler than those typical of *Pseudotsuga menziesii*-dominated stands are considered, *Thuja plicata*, *Tsuga heterophylla*, *Abies grandis*, *A. procera*, and *A. amabilis* become more important as temperatures drop (Zobel et al. 1976). *Abies magnifica* var. *shastensis* and *Tsuga mertensiana* occupy the coolest forested environments in the eastern Siskiyou Mountains (Cleary and Waring 1969).

Farther north, timberline for *Abies amabilis* in British Columbia is about 150 m (492 ft) lower than timberline for *Tsuga mertensiana*, *Abies lasiocarpa*, and *Pinus albicaulis* (Krajina 1970). Using controlled temperatures, Brix (1972) found *Picea glauca* to be more productive than *P. sitchensis* under high temperature - high light conditions.

A complete ranking of the mean temperature relations of northwestern tree species has not been attempted, but approximate relationships based upon available information are summarized in table 4. The approximate accuracy of field observation is associated with a Rocky Mountain ranking of species susceptibility to "red belt" injury (Mason 1915):

Juniperus sp. (most resistant)
Abies lasioca
Picea enaelmanni
[illegible]
Pseudotsuga menziesii
inus ponderosa (least resistant)

Red belt injury apparently results from crown desiccation that occurs when high needle transpiration is accompanied by frozen ground conditions that prevent water uptake. As such, it is a combination of temperature and moisture phenomena.

MOISTURE

Moisture comparisons among species may be considered in three categories: tolerance of deficient moisture, tolerance of excess moisture, and optimum moisture conditions. If quantity of published information is any indication of the relative importance of these categories, ability to endure deficient moisture (drought tolerance) is most important.

Table 4--Mean temperature relationships among northwestern tree species1/

Pinus ponderosa, *Quercus kelloggii*, *Quercus garryana*, *Arbutus menziesii*
Pseudotsuga menziesii, *Pinus lambertiana*, *Libocedrus decurrens*, *Acer* [illegible]
Thuja plicata
Tsuga heterophylla
Abies grandis
Abies amabilis, *A. procera*, *A magnifica* var. *shastensis*
Tsuga mertensiana, *Abies lasiocarpa*, *Pinus albicaulis*
Pinus contorta
Picea mariana, *P. glauca*, *Larix laricina*

1/ Compiled from information published by Hustich (1953), Steinbrenner and Rediske (1964), Pharis et al. (1967), Waring (1969), Cleary and Waring (1969), Krajina (1970), Brix (1971), and Zobel et al. (1976). Species adapted to warm temperatures are listed above those adapted to cool temperatures. Species in the same group are not necessarily equal, but data are insufficient for their separation.

DROUGHT TOLERANCE

Dry conditions may be endured by trees; or they may be avoided (by rapid and deep root growth, for example). In either case, several physiological attributes contribute to drought tolerance. Unfortunately, related attributes do not always coincide with overall tolerance and different researchers do not always agree. This is particularly true of the drought endurance associated with stomatal closure. Hodges (1967) found that *Abies procera* stomata closed more completely than *Pseudotsuga menziesii* stomata at night...and *P. menziesii* stomata closed more completely than *Tsuga heterophylla* and *Picea sitchensis*. *Abies concolor* stomata did not close at all. Hodges and Scott (1968) concluded that *A. procera* controlled internal moisture better than the other species. Running (1973, 1976) noted that *A. procera* showed little stomatal control, however, whereas *Pseudotsuga menziesii* and *A. concolor* appeared to have good control. When the data and conclusions of different researchers differ so, it is difficult to integrate them. In this case, characteristics of the environments in which the species normally occur make Running's conclusions seem more appropriate than those of Hodges and Scott.

Lopushinsky (1969) also studied stomatal closure. He found that *Pinus ponderosa, P. contorta,* and *Picea engelmannii* stomata closed sooner than those of *Pseudotsuga menziesii* and *Abies grandis*. Wambolt (1973), in a study of conifer water potential, concurred with Lopushinsky in ranking *Pinus ponderosa* stomatal control as more sensitive than that of *P. contorta, Picea engelmannii,* and *Pseudotsuga menziesii*.

Barker (1973) observed less stomatal control in *Abies concolor* than in *Pinus ponderosa* under comparable environmental conditions, but Rutter (1977), working with foliar samples exposed to full sunlight in the field, recorded more stomatal control in *A. concolor*. He found *Libocedrus decurrens* stomata to be more sensitive to increasing moisture stress than those of *A. concolor* or *P. ponderosa* and attributed its drought tolerance to stomatal control, suggesting that the long tap root of *P. ponderosa* allows it to avoid moisture stress rather than tolerate it. Rutter worked with day-to-day fluctuations that resulted in few common environmental conditions for the three species studied, however; and he did not attempt to account for within tree, between tree, or seasonal differences in behavior. Perhaps these unmeasured variables affect Rutter's *Pinus ponderosa* observations. Cleary (1971) observed an abrupt decline in *P. ponderosa* photosynthesis at moderate plant moisture stress (15-20 atm), a gradual decline in *Pseudotsuga menziesii* photosynthesis over a much wider range (<8->22 atm). Both declines probably were associated with stomatal closure.

Stomatal closure has not been studied in all northwestern tree species, but drought tolerance as such has been widely studied and observed (table 5). This may be just as well, for as Parker (1969) observed, whole seedlings involve other adaptations that may be more important than leaf resistance alone.

Franklin and Dyrness (1973) ranked *Quercus garryana* as the most moisture-stress tolerant southwestern Oregon major tree species, followed by *Quercus kelloggii, Pinus ponderosa,* and *Arbutus menziesii*. They did not rank *P. jeffreyi*, but Stone (1957), studying the effect of artificial dew on the survival of four western conifers, observed that unwatered seedlings of *P. jeffreyi* in greenhouse cans survived longer than unwatered *P. ponderosa, Libocedrus decurrens,* or *Abies concolor* seedlings. When he applied artificial dew in the form of a nightly water spray, *A. concolor* still died first, followed by the pines (together) and finally *L. decurrens*. Stone qualified his results by pointing out that greenhouse behavior may not duplicate that in the field, where differences in relative root growth rates among species might alter the relative drought resistance observed in greenhouse containers. Nevertheless Haller (1959) noted that *Pinus jeffreyi* is more tolerant of aridity

Table 5--Comparative drought tolerances of northwestern tree species[1]

Quercus garryana
Quercus kelloggii
Pinus jeffreyi
Pinus ponderosa
Pinus contorta, Libocedrus decurrens, Arbutus menziesii
Pseudotsuga menziesii
Picea engelmannii
Abies grandis
Pinus lambertiana, Larix occidentalis
Abies lasiocarpa, Thuja plicata, Pinus monticola
Abies concolor, Picea breweriana
Chamaecyparis lawsoniana
Tsuga heterophylla, Picea sitchensis
Abies amabilis
Abies magnifica var. *shastensis, Tsuga mertensiana*

[1]Compiled from information published by Daubenmire (1943), Tarrant (1953), Stone (1957), Haller (1959), Cochran (1963), Pharis (1966), Fraser and Cordes (1967), Kotar (1972), Franklin and Dyrness (1973), and Edmonds (1975). Drought tolerant species are listed above intolerant ones. Where species occur on the same line, information is insufficient to separate them.

than *P. ponderosa* in California. Tarrant (1953), comparing the characteristics of *P. ponderosa* and *P. contorta* in a literature review, attributed more drought tolerance to *P. ponderosa*. *P. ponderosa* also has a greater physiological capacity to exploit hot, dry environmental conditions than *L. decurrens* (Edmonds 1975) or *Pseudotsuga menziesii* (Daubenmire 1943, Daubenmire and Deters 1947, Parker 1951, and Cochran 1963).

Further comparisons involving *P. menziesii* are numerous. Marshall (1931), measuring critical soil moisture and survival, observed that *P. menziesii, Abies grandis,* and *Thuja plicata* survived with less soil moisture than that required by *Pinus monticola, Tsuga heterophylla,* or *Picea glauca.* Although transpiration rates declined faster in *Picea engelmannii* than in *Pseudotsuga menziesii* and *Abies grandis* when potted seedlings were subjected to moderate soil moisture stresses by Lopushinsky and Klock (1974), Daubenmire (1943) observed that *Pseudotsuga menziesii* survived longer than *Picea engelmannii* and *P. engelmannii* survived longer than *Abies lasiocarpa* or *Thuja plicata* when his potted seedlings were maintained at or below the wilting point for 2, 4, 6, 8, and 10 days. Using diurnal variations in sap pressure and dormancy as their criteria. Fraser and Cordes (1967) rated *Pseudotsuga menziesii* more able to avoid moisture stress than *Tsuga heterophylla* or *Picea sitchensis.*

When Parker (1951) cut leaves from several tree species and measured moisture retention, *Pseudotsuga menziesii* leaves retained a higher moisture content than those of *Picea engelmanni, Thuja plicata, Abies grandis,* or *Pinus monticola.* Measuring foliage moisture content and soil moisture stress, Pharis (1966) ranked *Pseudotsuga menziesii* and *Libocedrus decurrens* above *A. grandis* and *A. grandis* above *Pinus lambertiana* in drought resistance. In considering these comparisons, it is important to remember that *P. menziesii* trees from different geographic localities... and even from different aspects... may differ in drought resistance (Pharis and Ferrell 1966, Ferrell and Woodward 1966). Similar variation probably occurs in other species.

Pinus lambertiana seems to be more drought tolerant than *P. monticola* in southwestern Oregon

(Franklin and Dyrness 1973); and *P. monticola* appears to be less able to adapt to inadequate soil moisture than *Pseudotsuga menziesii*, *Abies grandis*, *Larix occidentalis*, or *Thuja plicata* in the western white pine type (Leaphart and Wicker 1966). Southwestern Oregon *Pinus lambertiana* also is more drought tolerant than *Picea breweriana*, which is quite tolerant of soil moisture stress but intolerant of evaporative demand (Waring et al. 1975). Waring et al. indicate that *Abies concolor* in southwestern Oregon slightly exceeds *P. breweriana* in ability to tolerate evaporative demand but is a little less tolerant of soil moisture stress. *Tsuga mertensiana* and *Abies magnifica* var. *shastensis* are much less tolerant of soil moisture deficiencies.

Franklin and Dyrness (1973) ranked *Chamaecyparis lawsoniana*, *Abies magnifica* var. *shastensis*, *Tsuga mertensiana*, and *T. heterophylla* below *Abies concolor* in decreasing order of moisture stress tolerance in southwestern Oregon. As Kotar (1972) found *T. heterophylla* to be more drought tolerant than *Abies amabilis* when seedlings of both species were subjected to high moisture stresses in the laboratory and as Lowry's 1972 laboratory measurements showed *A. amabilis* to be more drought tolerant than *Tsuga mertensiana*, Franklin and Dyrness's *Tsuga* rankings probably should be reversed. *Tsuga heterophylla* seems to be more drought tolerant than *T. mertensiana*. Puritch (1973) in comparing the effect of water stress on photosynthesis, respiration, and transpiration of four *Abies* species, found *A. grandis* to be most stress tolerant, followed by *A. lasiocarpa*, *A. amabilis*, and *A. balsamea*--in that order.

EXCESS MOISTURE

Excess moisture usually is the result of flooding or the presence of a shallow water table in nature. Observations of flood mortality, through sometimes confounded by other factors, often provide the only available species comparisons. Brink (1954), observing the results of a 1948 spring flood in the lower Fraser River Valley, found *Picea sitchensis*, *Pinus contorta*, and *Thuja plicata* mortality to be lower than that of *Tsuga heterophylla*. *T. heterophylla* mortality was lower than that of *Pseudotsuga menziesii* or *Alnus rubra*. Krajina (1970) observed that *Populus trichocarpa*, *P. tremuloides*, *Abies grandis*, *A. lasiocarpa*, *Thuja plicata*, *Picea sitchensis*, *P. engelmannii*, *P. glauca*, and *Tsuga heterophylla* survive on floodplain habitats where *Pseudotsuga menziesii* cannot grow. *Sequoia sempervirens* and *Umbellularia californica* survive flooding that kills *P. menziesii*, *A. grandis*, and *Lithocarpus densiflora* (Stone and Vasey 1968).

Controlled flooding experiments indicate that *Pinus contorta* is more tolerant of oxygen deficiency than is *Picea sitchensis* (Boggie 1974, Crawford and Baines 1977), surviving better when seedlings of both species are artificially flooded (Minore (1968). Minore also found *Pinus contorta* and *Thuja plicata* seedlings to be more flood tolerant than those of *Alnus rubra* and *Tsuga heterophylla*, which were more tolerant than *Pseudotsuga menziesii* seedlings. Gill (1970), however, emphasized in his excellent flooding review that it probably is not permissible to extrapolate from seedling performance to mature trees when dealing with flood tolerance. Physical size may be very important.

Soil characteristics apparently influence species tolerance of shallow water tables in nature. Howell (1931) found *Pinus contorta* in the saturated soil over hard pan areas in California and claimed that *P. ponderosa* could not endure such excess moisture. Like Howell, Tarrant (1953) concluded that *P. contorta* was very tolerant of continuous high soil moisture but *P. ponderosa* was intolerant. In contrast, Stephens (1965) observed that *P. ponderosa* thrived on imperfectly drained soils with clay subsoils developed from Eocene to Miocene volcanic rocks in the western Cascade Mountains of Oregon, growing better than *Pseudotsuga menziesii* or *Pinus lambertiana* on these moist, fine-textured substrates. The Eocene to Miocene

parent materials seem to be uniquely effective in favoring *P. ponderosa* on wet sites. More than moisture must be involved, for Cochran (1972) obtained no significant mortality in either *P. ponderosa* or *P. contorta* when he subjected seedlings to carefully controlled shallow water-table conditions in a greenhouse. Haller (1959) indicated that *P. jeffreyi* is at least as tolerant of high moisture as *P. ponderosa.*

Minore and Smith (1971), reporting on the occurrence and growth of four tree species in swamps and stream bottoms on the Olympic Peninsula, ranked *Alnus rubra* and *Thuja plicata* as most tolerant of shallow water tables, followed by *Picea sitchensis* and (least tolerant) *Tsuga heterophylla.* Absence of *Pseudotsuga menziesii* in these wet habitats indicated even less tolerance than *T. heterophylla.* When Minore (1970) compared the seedling growth of eight species over artificial water tables, he found *Pinus contorta, Thuja plicata, Alnus rubra,* and *Picea sitchensis* to be more tolerant of shallow water tables than *Pseudotsuga menziesii.* These and other excess-moisture tolerance relationships are summarized in table 6.

OPTIMUM MOISTURE

Optimum moisture conditions are difficult to determine in controlled growthchamber or greenhouse environments. Other environmental factors influence species growth, and the resulting interactions often are difficult to identify and analyze. Where optimum conditions are defined on the basis of natural range comparisons in the field, further difficulties arise. Competition from other species may influence the species range under consideration, and the observed moisture range may not be the optimum range. Nevertheless, the results of controlled-environment experiments where moisture conditions for the maximum growth of two or more species are compared would provide useful information, and species occurrences along moisture gradients in nature probably reflect their moisture optima in a relative sense.

Controlled-environment experiments involving moisture conditions for maximum growth seem to be almost non-existent. Steinbrenner and Rediske (1964), however, did find that *Pseudotsuga menziesii* seedlings were more responsive to high levels of moisture and humidity than *Pinus ponderosa* seedlings.

A few investigators have observed species presence along measured moisture gradients in the field. Waring and Major (1964) ranked 10 northwestern species in coastal northern California by assigning "ecological optimum" numbers along a scale of 0 (dry) to 100 (wet): *Libocedrus decurrens* (on serpentine soil)--0, *Quercus kelloggii* and *Q. garryana*--10, *Pseudotsuga menziesii*--

Table 6--Comparative tolerances of northwestern tree species to excess moisture[1/]

Pinus contorta, Thuja plicata, Tsuga mertensiana, Chamaecyparis nootkatensis, Abies lasiocarpa, Sequoia sempervirens, Populus trichocarpa, Umbellularia californica
Alnus rubra
Pinus ponderosa, P. jeffreyi, Picea sitchensis, Abies grandis
Tsuga heterophylla
Pseudotsuga menziesii

[1/] Compiled from information published by Howell (1931), Brink (1954), Wood (1955), Haller (1959), Stone and Vasey (1968), Minore (1968, 1970), Krajina (1970), Minore and Smith (1971), Boggie (1974), and Crawford and Baines (1977). Moisture tolerant species are listed above intolerant ones. Where species occur in the same group, information is insufficient to separate them.

17, *Arbutus menziesii*--20, *Lithocarpus densiflora*--25, *Sequoia sempervirens*--62, *Alnus rubra*--78, *Acer macrophyllum*--85, and *Populus trichocarpa*--100. Waring (1969) also positioned major forest vegetation types of the eastern Siskiyou Mountains of southwestern Oregon along a gradient from dry (*Quercus kelloggii*) to wet (*Abies magnifica* var. *shastensis* and *Tsuga mertensiana*). Farther north, in the central western Cascade Range of Oregon, Zobel, et al. (1976) ranked tree species distribution along a plant moisture stress gradient. In order, the species are: *Arbutus menziesii* (dry), *Libocedrus decurrens* and *Pinus lambertiana*, *Acer macrophyllum* and *Pseudotsuga menziesii*, *Tsuga heterophylla* and *Thuja plicata*, *Abies grandis*, *Abies procera* and *A. amabilis*, and *Tsuga mertensiana* (wet).

Most comparisons of optimum moisture conditions among northwestern tree species consist of somewhat subjective statements based upon careful observation and field experience. Species that grow in moist conditions often are compared to *Pseudotsuga menziesii* in these statements. For example, *Tsuga heterophylla*, *Thuja plicata*, *Abies procera*, *A. amabilis*, and *Picea sitchensis* all require more moisture than *Pseudotsuga menziesii* (see Munger 1940, Forest Soils Committee of the Douglas-fir Region 1957, and Aller 1956). Comparisons among two or three species provide more detail and help to refine these rather broad contrasts. They have been combined whenever possible and summarized in table 7.

Day (1957) suggested that *Thuja plicata* requires more moisture than *Picea sitchensis* or *Tsuga heterophylla*. Habeck (1968) observed *T. heterophylla* dominating *Thuja plicata* on well-drained slopes, *T. plicata* dominating *T. heterophylla* on poorly drained depressions and wet ravines in Glacier National Park. Wood (1955) noted that *Picea sitchensis* dominated *T. heterophylla* on moist sites but not on dry ones in southeastern Alaska. Combining the observations of these three authors, one can rank the three species in order: *Thuja plicata* (very moist), *Picea sitchensis*, and *Tsuga heterophylla* (less moist). Furthermore, the information presented by Zobel et al. (1976) indicates that *Thuja plicata* prefers slightly drier habitats than *Tsuga mertensiana*, *Abies amabilis*, and *A. procera*. Zobel and Hawk's (see footnote 2, page 5) observations suggest that

Table 7--Optimum moisture relationships among northwestern tree species[1/]

Tsuga mertensiana, *Abies amabilis*, *A. procera*, *A. magnifica* var. *shastensis*, *A. concolor*, *Populus trichocarpa*
Abies grandis
Thuja plicata
Picea sitchensis
Tsuga heterophylla
Acer macrophyllum
Alnus rubra
Pseudotsuga menziesii
Pinus ponderosa
Pinus lambertiana, *Libocedrus decurrens*
Arbutus menziesii
Quercus garryana, *Quercus kelloggii*

[1/] Compiled from information published by Munger (1940), Wood (1955), Day (1957), Forest Soils Committee (1957), Steinbrenner and Rediske (1964), Thilenius (1964), Aller (1956), Habeck (1968), Newton et al. (1968), Waring and Major (1964), and Zobel et al. (1976). Species with moist optimums are listed above those with dry optimums. Where species occur in the same group, information is insufficient to separate them.

Chamaecyparis lawsoniana may require more moisture than *Pseudotsuga menziesii*. Combining and comparing observations made in different areas in this way introduces an unknown amount of ecotypic variation, but species comparisons often are not possible otherwise.

Abies lasiocarpa requires moister habitats than *Picea engelmannii* (Smith and Clark 1960, Krajina 1970) or *Pinus contorta* (Wali and Krajina 1973). Further examination of the literature indicates that *P. engelmannii* requires more moisture than *P. contorta*, and *P. contorta* requires more moisture than *Pseudotsuga menziesii* or *Pinus ponderosa* (Tackle 1959). *Pinus contorta* requires less drainage than *P. ponderosa* (Kerr 1913), and it makes better growth than *P. ponderosa* on wet sites (Youngberg and Dyrness 1959). Unfortunately, information relating *Pinus contorta*, *Abies lasiocarpa*, and *Picea engelmannii* to other species is lacking.

Some information is available for northwestern hardwoods. According to the previously cited ecological optima of Waring and Major (1964), *Acer macrophyllum* prefers slightly more moisture than *Alnus rubra*. Both of these species appear to be suited to slightly more moist sites than *Pseudotsuga menziesii* (Thilenius 1964, Newton et al. 1968). *Lithocarpus densiflora* requires more moisture than *Arbutus menziesii*, *Quercus garryana*, or *Q. kelloggii* (Roy 1962).

NUTRIENTS

MACRONUTRIENT CONCENTRATIONS

Relative foliage, wood, bark, and litter concentrations of the mineral elements necessary for plant growth apparently differ among northwestern tree species. These concentrations vary somewhat with soils and season, so concentration differences may or may not reflect relative species nutrient requirements. Nevertheless, they do influence the environments in which they occur. Different species contribute differing kinds and quantities of nutrient material to their surroundings. Some of these difference have been extracted from the literature and ranked as relative macronutrient concentrations in table 8.

Working on several soils, Daubenmire (1953) measured the nutrient content of freshly fallen foliage from 12 northern Rocky Mountain species--species that also occur in the Pacific Northwest. He suggested that the high calcium content of *Thuja plicata* litter was at least partly responsible for the higher pH of soil measured under this species. Surprisingly, the even higher calcium content of *Abies grandis* litter produced no such effect. Alban (1969) measured higher soil pH, exchangeable calcium, cation-exchange capacity, base saturation, and organic matter under old *Thuja plicata* than under old *Tsuga heterophylla* trees.

Tarrant et al. (1951) also worked on several soils when they measured nutrients in the annual litter fall of 10 northwestern tree species, but Webber (1973) studied young trees on a single soil type. He measured higher calcium contents in *Thuja plicata* than in either *Tsuga heterophylla* or *Pseudotsuga menziesii*. Webber's data, like those recorded for young seedlings by Lavender (1962) but unlike the information published by Tarrant et al. (1951), Daubenmire (1953), and Ovington (1956), show *Tsuga heterophylla* to have more calcium than *Pseudotsuga menziesii*. Soil diversity and ages of the trees, foliage, and litter sampled may be responsible for these differences. When mature trees are analyzed, calcium concentrations seem to be higher in *Pseudotsuga menziesii* than in *Tsuga heterophylla*.

Regardless of soil or age, there seems to be little doubt of the high calcium characteristic of *Thuja plicata*. Beaton, Moss et al. (1965) found calcium content to be higher in *T. plicata* foliage than in the foliage of forest grown *Abies lasiocarpa*, *A. amabilis*, *Pseudotsuga menziesii*, *Tsuga heterophylla*, *Picea sitchensis*, or *P. engelmannii*; and Ovington (1956) found both *Thuja plicata* and *Chamaecyparis lawsoniana* leaves to be richer in calcium than those of *Pseudotsuga menziesii* or *Tsuga heterophylla*. The *Thuja* and *Chamaecyparis* leaves and litter layers also had higher

Table 3--Relative macronutrient concentrations in northwestern tree species[1]

Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur
Alnus rubra	*Larix occidentalis*	*Populus tremuloides*	*Abies grandis*	*Picea sitchensis*	*Pseudotsuga menziesii*
Abies amabilis	*Populus tremuloides*	*Acer macrophyllum*	*Populus tremuloides*	*Pinus ponderosa, P. contorta, P. monticola*	*Tsuga heterophylla*
Picea sitchensis	*Pseudotsuga menziesii*	*Alnus rubra*	*Thuja plicata, Abies amabilis*	*Abies amabilis, Tsuga heterophylla*	*Thuja plicata*
Acer macrophyllum	*Alnus rubra, Tsuga heterophylla, Abies lasiocarpa*	*Pinus ponderosa*	*Acer macrophyllum*	*Thuja plicata*	
Pinus contorta	*Abies amabilis, Pinus ponderosa, P. monticola, P. albicaulis, Abies grandis, Picea engelmannii, Acer macrophyllum*	*Pseudotsuga menziesii, Larix occidentalis*	*Pseudotsuga menziesii*	*Pseudotsuga menziesii*	
Populus tremuloides	*Picea sitchensis*	*Abies grandis*	*Picea engelmannii*	*Acer macrophyllum*	
Abies lasiocarpa	*Thuja plicata*	*Thuja plicata*	*Abies lasiocarpa*	*Alnus rubra*	
Abies grandis	*Pinus contorta*	*Pinus contorta*	*Abies amabilis*		
Pseudotsuga menziesii		*Tsuga heterophylla*	*Alnus rubra*		
Picea engelmannii		*Abies magnifica var. shastensis, Picea engelmannii*	*Pinus monticola*		
Pinus ponderosa		*Pinus monticola*	*Pinus contorta, Tsuga heterophylla*		
Tsuga heterophylla		*Abies amabilis, Picea sitchensis*	*Picea sitchensis*		
Pinus albicaulis		*Pinus albicaulis*	*Larix occidentalis*		
Larix occidentalis			*Pinus ponderosa*		
Thuja plicata			*Pinus albicaulis*		

[1] Compiled from foliage, wood, bark, and litter data published by Tarrant et al. (1951), Daubenmire (1953), Ovington (1956), Wollum and Youngberg (1964), Beaton, Moss et al. (1965), van den Driessche (1969), and Webber (1973). Species are ranked from high concentration (top) to low concentration (bottom) in these lists. Species in the same group are not necessarily equal, but data are insufficient for species comparisons within groups.

pH values. *Chamaecyparis lawsoniana* leaf nutrient concentrations are similar to those found in *Thuja plicata*, except for higher magnesium (Zobel and Hawk undated).

Although *Thuja plicata* sapwood has more calcium than *Pseudotsuga menziesii*, it does not differ significantly from *Tsuga heterophylla* or *Alnus rubra* with respect to sapwood calcium content (Radwan 1969). Radwan's data show that *A. rubra* sapwood has more nitrogen and magnesium, but less iron than that of *Thuja plicata*, *Tsuga heterophylla*, or *Pseudotsuga menziesii*. Relative sapwood and foliage concentrations probably differ when species are compared, for the data of Tarrant et al. (1951) show *A. rubra* foliage to have less magnesium than other species.

Tarrant et al. (1951), Daubenmire (1953), and Wollum and Youngberg (1964) all found *Pinus ponderosa* litter to be lower than *Pseudotsuga menziesii* litter in calcium and nitrogen contents. *Thuja plicata* also ranked below *P. menziesii* with respect to nitrogen concentration. Indeed, published data indicate that *T. plicata* may have the lowest nitrogen content of any northwestern tree species (Tarrant et al. 1951, Daubenmire 1953, Beaton, Moss et al. 1965, and Webber 1973). In contrast, *Alnus rubra* may be top ranked for nitrogen content (Tarrant et al. 1951, Wollum and Youngberg 1964). *Abies amabilis*, *Acer macrophyllum*, *Picea sitchensis*, and *Pinus contorta* also have high nitrogen contents. *Picea sitchensis* seedlings, though higher in nitrogen concentration, have less phosphorus than *Pseudotsuga menziesii* seedlings of similar age when grown in sand culture (van den Driessche 1969).

Larix occidentalis seems to have the highest phosphorus concentration, *Pinus contorta* the lowest (Tarrant et al. 1951, Daubenmire 1953). *Populus tremuloides* heads the list for potassium; *Pinus albicaulis* places last (Dabenmire 1953). *Thuja plicata* foliage apparently has less sulfur than the foliage of *Abies lasiocarpa*, *A. amabilis*, *Pinus contorta*, *Picea engelmannii*, *P. sitchensis*, *Pseudotsuga menziesii*, or *Tsuga heterophylla*; and *T. heterophylla* foliage seems to have slightly less sulfur than that of *P. menziesii* Beaton, Moss et al. 1965).

MICRONUTRIENT CONCENTRATIONS

Micronutrient levels in foliage often are influenced by "luxury consumption," and may reflect soil differences rather than species differences. When Landis (1976) compared foliage nutrient levels in "ideal" seedlings of three Rocky Mountain tree species growing in the same Colorado nursery, however, he found manganese concentrations to be higher in *Picea engelmannii* than in *Pinus contorta* or *P. ponderosa*. Zinc and boron concentrations were higher in *P. contorta* than in *P. ponderosa* or *Picea engelmannii* in these nursery seedlings. Beaton, Brown, et al. (1965), measured micronutrient concentrations in the foliage of three British Columbia conifers. They found that manganese and aluminum levels tended to be higher in *Tsuga heterophylla* needles than in those of *Pseudotsuga menziesii*, which had much more silica than *T. heterophylla*. *P. menziesii* also may have more silica (and less potassium) than *Arbutus menziesii* (Young 1974). Unfortunately, Young's analyses were based on only one tree of each species, and replicated *Pseudotsuga*-*Arbutus* comparisons are not available.

NUTRIENT DEFICIENCY TOLERANCES

Species tolerances of nutrient deficiencies or excesses and differing species growth responses to various nutrient conditions probably are of more immediate concern than species nutrient concentrations. Relative tolerances of nutrient. deficiences are listed in table 9.

Nitrogen deficiencies are best tolerated by *Picea sitchensis*, least tolerated by *Thuja plicata*, *Pinus monticola*, and *P. ponderosa* (Krajina 1970). *Pseudotsuga menziesii* var. *menziesii* also is intolerant of nitrogen deficiencies (Murison 1961). Nitrogen stimulates its shoot growth in relation to root growth but does just the opposite for *Thuja plicata*, decreasing top growth in relation to root growth (Smith et al. 1968).

Table 9--Relative tolerance of macronutrient deficiencies in northwestern tree species[1/]

Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur
Picea sitchensis	*Pinus ponderosa*, *P. monticola*, *Tsuga heterophylla*, *Thuja plicata*	*Picea engelmannii*	*Tsuga heterophylla*	*Tsuga heterophylla*	*Picea engelmannii*
Tsuga heterophylla	*Pseudotsuga menziesii* var. *menziesii*	*Pseudotsuga menziesii* var. *menziesii*	*Picea sitchensis*	*Pseudotsuga menziesii* var. *menziesii*	*Pseudotsuga menziesii* var. *glauca*
Pseudotsuga menziesii	*Pseudotsuga menziesii* var. *glauca*	*Pinus monticola*	*Pseudotsuga menziesii*	*Pinus monticola*	*Pinus monticola*
Thuja plicata, *Pinus monticola*, *P. ponderosa*	*Picea sitchensis*	*Pinus ponderosa*	*Pinus monticola*, *Thuja plicata*, *Chamaecyparis nootkatensis*, *Pinus ponderosa*	*Pseudotsuga menziesii* var. *glauca*	*Pseudotsuga menziesii* var. *menziesii*
		Pseudotsuga menziesii var. *glauca*		*Picea sitchensis*	*Pinus ponderosa*
				Thuja plicata, *Chamaecyparis nootkatensis*	

[1/] Most of the information used in compiling this table was obtained from Krajina (1959, 1970). Tolerant species are listed above intolerant species. Information is insufficient to separate species grouped together.

Picea sitchensis growth is stimulated more than *Pseudotsuga menziesii* growth by high nitrogen levels (van den Driessche 1968), and *P. sitchensis* should surpass *P. menziesii* on high-nitrogen, coastal sites.

Psuedotsuga menziesii is less tolerant of phosphorus deficiences than *Pinus ponderosa, P. monticola, Tsuga heterophylla,* or *Thuja plicata* (Krajina 1970). It is more tolerant of low phosphorus than *Picea sitchensis* (van den Driessche 1968, Krajina 1970) or *P. engelmannii* (Murison and Krajina, summarized in Krajina 1970).

Pseudotsuga menziesii var. *menziesii* tolerates phosphorus, potassium, and magnesium deficiencies better than *P. menziesii* var. *glauca,* but is less tolerant of low sulfur (Krajina 1970). Krajina and his co-workers have shown *Tsuga heterophylla* to be more tolerant of calcium and magnesium deficiens than *P. menziesii,* while *Thuja plicata* is less tolerant. Using a "replacable calcium gradient" Waring and Major (1964) ranked *Libocedrus decurrens* as more tolerant of calcium deficiencies than either *P. menziesii* or *Arbutus menziesii.*

Although comparative species responses to nutrient deficiencies apparently vary with the deficient nutrient, several authors have compared the general tolerance of two or more northwestern tree species to all nutrient deficiencies.

In general, *Tsuga heterophylla* seems to be more tolerant of soil nutrient deficiencies than *Pseudotsuga menziesii* (Krajina 1970, Heilman and Ekuan 1973), *Abies amabilis* (Krajina 1970), or *A. grandis* (Aldhous and Low 1974). Indeed, *T. heterophylla*'s soil nutrient requirements are among the lowest known for any coniferous tree (Krajina 1970). Although they often grow on ultramafic soils and are not directly compared with *T. heterophylla* in the literature, *Picea breweriana* and *Pinus jeffreyi* may be comparable to it with respect to nutrient deficiencies--they are more tolerant of low fertility than *Abies concolor, A. magnifica* var. *shastensis, Pinus lambertiana, Pseudotsuga menziesii,* or *Tsuga mertensiana* (Waring et al. 1975).

Pseudotsuga menziesii (Gessel et al. 1951) and *Abies amabilis* (Krajina 1970) tolerate poorer nutrient conditions than *Thuja plicata. Pinus lambertiana* is more sensitive than *Pseudotsuga menziesii* to poor supplies of calcium and magnesium (Krajina 1970), but it is better able to utilize infertile ultrabasic soils than *Abies magnifica* var. *shastensis* or *Tsuga mertensiana* (Waring 1970). Infertile soils also are better utilized by *Pinus contorta* than by *Abies lasiocarpa* (Wali and Krajina 1973).

NUTRIENT EXCESSES

Nutrient excesses may be just as limiting as deficiencies, but they occur less frequently. Along the Pacific Coast, *Picea sitchensis* is able to tolerate the excess magnesium in sea spray better than *Tsuga heterophylla* and other conifers (Krajina 1970). Applications of lime are tolerated by *Pseudotsuga menziesii* better than by *T. heterophylla* (Heilman and Ekuan 1973), and *Thuja plicata* is more tolerant of excess calcium than other northwestern trees (Aldhous and Low 1974). *Thuja plicata* also is more tolerant of alkaline soils than *Picea sitchensis, Tsuga heterophylla,* or *Pinus contorta* (Benzian 1965). Acidic soils are tolerated better by *Tsuga heterophylla* than by *Pseudotsuga menziesii* (Heilman and Ekuan 1973).

AMMONIUM VS. NITRATE NITROGEN

In addition to nutrient quantities (deficiencies, optimal amounts, or excesses), nutrient qualities and chemical formulations are important when comparing the survival and growth of tree species. Nitrogen is particularly noteworthy in this respect. Ammonium nitrogen is tolerated by seedlings of *Tsuga heterophylla* (Taylor 1935, Krajina 1970 and 1971, Madoc-Jones 1970, Heilman and Ekuan 1973) and *Pinus contorta* (Madoc-Jones 1970, Krajina 1971). Van den Driessche (1971) found that *Pseudotsuga menziesii* seedlings grew better with ammonium nitrogen than with nitrate nitrogen;

but Krajina et al. (1973) recorded contrary results...their *P. menziesii* and *Pinus contorta* seedlings grew better when supplied with nitrate nitrogen. Mycorrhizal differences may be responsible for these differing results. Without mycorrhizae, nitrates are relatively poor sources of nitrogen for *Pseudotsuga menziesii* seedlings, and growth is better with ammonium nitrate (Li et al. 1972). *Alnus rubra* grows better than *P. menziesii* without mycorrhizae or ammonium, for *A. rubra* roots are capable of reducing nitrate. *P. menziesii* roots are not (Li et al. 1972).

A mixture of both ammonium and nitrate nitrogen appears to be best for *Picea engelmannii* (Krajina 1970), *P. sitchensis* (van den Driessche 1971), *Thuja plicata* and *Tsuga heterophylla* (Krajina et al. 1973). *Abies amabilis, A. grandis,* and *Chamaecyparis nootkatensis* seem to prefer nitrate nitrogen.

MYCORRHIZAL RELATIONSHIPS

A review of autecological characteristics would be incomplete without further mention of mycorrhizae, for most woody plants depend upon mycorrhizal fungi for absorption of nutrients from the soil (Trappe 1977). Many species of mycorrhizal fungi are involved. Only three mycorrhizal types occur on northwestern trees, however--the vesicular-arbuscular mycorrhizae, the ectomycorrhizae + ectendomycorrhizae, and the ericoid mycorrhizae.[3] Individual trees usually have several species of mycorrhizal fungi on their roots (Trappe 1977), but these species tend to be all of the same mycorrhizal type...and different tree species support different types (table 10).

Trappe (1977) demonstrated with *Pinus ponderosa, Tsuga heterophylla* and *Pseudotsuga menziesii* that different host species can react differently to a given mycorrhizal fungus. In Trappe's experiment, inoculation with pure cultures of four mycorrhizal fungi increased *T. heterophylla* seedling weights, but not the weights of *P. ponderosa* or *Pseudotsuga* seedlings. Similar data on the mycorrhizal responses of other northwestern tree species have been published, but they are too scanty and variable as yet to provide much useful information. The autecological characteristics of mycorrhizal fungi need further study before they can be related to the autecological characteristics of northwestern tree species in more detail.

[3] James M. Trappe, Forestry Sciences Laboratory, Corvallis, Oreg. Personal communication, June 1978.

Table 10--Types of mycorrhizae associated with northwestern tree species[1]

Vesicular-arbuscular mycorrhizae	Ectomycorrhizae + ectendomycorrhizae	Ericoid mycorrhizae
Acer macrophyllum	*Abies amabilis*	*Arbutus menziesii*
Acer negundo	*Abies concolor*	
	Abies grandis	
Chamaecyparis lawsoniana	*Abies lasiocarpa*	
Chamaecyparis nootkatensis	*Abies magnifica*	
	Abies magnifica var. *shastensis*	
	Abies procera	
Fraxinus oregona		
	Alnus rubra	
Juniperus occidentalis		
Juniperus scopulorum	*Betula papyrifera*	
Libocedrus decurrens	*Castanopsus chrysophylla*	
Populus balsamifera	*Larix laricina*	
Populus tremuloides	*Larix lyalli*	
Populus trichocarpa	*Larix occidentalis*	
Sequoia sempervirens	*Lithocarpus densiflora*	
Taxus brevifolia	*Picea breweriana*	
	Picea engelmannii	
Thuja plicata	*Picea glauca*	
	Picea mariana	
Umbellularia californica	*Picea sitchensis*	
	Pinus albicaulis	
	Pinus attentuata	
	Pinus contorta	
	Pinus jeffreyi	
	Pinus lambertiana	
	Pinus monticola	
	Pinus ponderosa	
	Populus balsamifera	
	Populus tremuloides	
	Populus trichocarpa	
	Pseudotsuga menziesii	
	Quercus chrysolepis	
	Quercus garryana	
	Quercus kelloggii	
	Tsuga heterophylla	
	Tsuga mertensiana	

1/ James M. Trappe, Forestry Sciences Laboratory, Corvallis, Oreg. Personal communication, June 1978.

GROWTH

Light, temperature, moisture, nutrients, and other environmental factors all influence growth rates; and species growth rates should not be treated as separate entities. Growth is the result of genetic-environmental interactions that vary with both species and environment. One can compare species under given environmental conditions and derive rankings based upon species growth in those conditions. For example, Godman (1949) found that *Picea sitchensis* diameter growth outstripped that of *Tsuga heterophylla* in coastal Alaska, and Johnstone (1976) measured faster juvenile height growth of *Pinus contorta* than of *Picea glauca* in west-central Alberta. Unfortunately, such local comparisons reflect differential species reactions to particular light, temperature, moisture, and/or nutrient conditions. They may not reflect species growth rates as such, for different species often grow differently in different environments.

Several examples illustrate the interactions between growth rate and environment. Walters, Soos, and Ker (1961) observed that *Thuja plicata* seedlings reached breast height faster than *Pseudotsuga menziesii* seedlings on good sites in British Columbia. On poor sites the species ranking was reversed, with *P. menziesii* seedlings growing fastest and *T. plicata* seedlings slowest. Walters and Haddock (1966) concluded that inherent species vigor is better expressed on high quality sites than on poor sites, and they rated *Tsuga heterophylla* as faster growing than *Thuja plicata* or *Abies amabilis*. Nevertheless, growth-site interactions are confusing.

Stein (1963) planted *Pinus ponderosa, P. lambertiana, Libocedrus decurrens, Pseudotsuga menziesii,* and *Abies grandis* seeds from the same seed sources on three kinds of soil in southwestern Oregon. The resulting seedling height growth comparisons differed with soil type...*Libocedrus decurrens* ranked first on one soil, fourth on another after one growing season. When Deitschman and Green (1965) related *Pinus monticola* site index and tree heights of several associated species in northern Idaho, they found that species height rankings varied with both site index and stand age. *Pseudotsuga menziesii* was taller than *Pinus monticola, Tsuga heterophylla,* or *Abies grandis* in 30-year-old stands of site index 40, shorter than these three species in 30-year-old stands of site index 80.

Clearly, ranking growth rates as such is impractical. Nevertheless, species do grow differently. Roots develop more rapidly in some than in others, seasonal shoot growth periods vary in length, mature sizes differ, and the species have different life spans. As recorded in the literature, these differences are summarized in table 11.

SEEDLING ROOT GROWTH RATE

Pinus ponderosa seedlings characteristically develop deep, sturdy root systems more rapidly than their associates (Pearson 1924, Stein 1955 and 1963, Tarrant 1953). *P. lambertiana* seedlings also develop root systems very rapidly. *Libocedrus decurrens* (Stein 1963) and *Pinus contorta* (Tarrant 1953) root development is somewhat slower.

Pseudotsuga menziesii, Abies grandis, Pinus monticola, and *Larix occidentalis* may be ranked next (see Haig et al. 1941, Stein 1955 and 1963). Seedling root growth rates in these species are faster than those of *Thuja plicata* and *Tsuga heterophylla* (Haig et al. 1941). As *Tsuga heterophylla* root penetration is poorer than that of *Thuja plicata* (Boyd 1959), it probably is also slower. *Tsuga heterophylla* probably is not the slowest species, however, for Ruth (1968a) found *Picea sitchensis* roots to be even shorter than those of *Tsuga heterophylla* after the first growing season.

Picea engelmannii seedlings produce roots more slowly than *Pseudotsuga menziesii* (Pearson 1924) or *Abies lasiocarpa* (Smith 1955) seedlings, and *Abies grandis* root growth is less than that for *P. menziesii* (Stein 1963, but

Table 11--Relative root growth rates, shoot growth periods, mature sizes, and longevity of northwestern tree species[1]

Seedling root growth rate[2]	Shoot growth period[3]	Size at maturity[3]		Longevity[4]
		Diameter	Height	
Pinus ponderosa, P. lambertiana	*Thuja plicata, Libocedrus* [illegible]	*Sequoia sempervirens*	*Sequoia sempervirens*	*Sequoia sempervirems, Thuja plicata, Chamaecyparis noot*[illegible]
Libocedrus decurrens, Pinus contorta	*Pinus ponderosa, P. jeffreyi, Chamaecyparis lawsoniana*	*Thuja plicata*	*Pseudotsuga menziesii*	*Picea sitchensis*
[illegible] *menziesii, Pinus monticola, Larix* [illegible]	*Tsuga heterophylla*	*Picea sitchensis*	*Picea sitchensis*	*Pseudotsuga menziesii*
[illegible]	*Picea sitchensis, P. glauca*	*Pseudotsuga menziesii*	*Abies procera*	*Larix occidentalis*
Tsuga hetero[illegible]	*Sequoia sempervirens*	*Chamaecyparis lawsoniana*	*Tsuga heterophylla*	*Pinus ponderosa*
Picea sitchensis	*Pinus contorta*	*Larix occidentalis*	*Thuja plicata*	*Chamaecyparis lawsoniana, Libocedrus decurrens, Picea engelmannii, Quercus garryana*
	Abies grandis	*Abies concolor, A. procera, Chamaecyparis nootkatensis*	*Chamaecyparis lawsoniana,* [illegible]*cola*	*Abies amabilis, A. procera, Pinus lambertiana, P. monticola, Tsuga heterophylla, T. mertensiana*
	Pseudotsuga menziesii	*Abies magnifica, Pinus lambertiana*	*Abies grandis*	*Abies concolor, A. grandis,* [illegible]*, Acer macrophyllum*
	Abies procera	[illegible] *decurrens, Tsuga hetero*[illegible]	*Abies amabilis, Pinus lambertiana*	*Abies lasiocarpa,* [illegible]
	Abies amabilis	*Pinus monticola*	*Larix occidentalis*	*Populus trichocarpa*
	Abies concolor, Pinus lambertiana	*Abies grandis, Pinus ponderosa*	*Picea engelmannii*	*Lithocarpus densiflora*
		Abies amabilis	*Abies concolor*	*Alnus rubra*
		Picea engelmannii	*Abies magnifica*	
		Tsuga mertensiana	*Libocedrus decurrens*	
		Populus trichocarpa	*Pinus ponderosa*	
		Lithocarpus densiflora	*Chamaecyparis nootkatensis, Alnus rubra*	
		Quercus garryana	*Abies lasiocarpa, Pinus contorta, Tsuga mertensiana, Populus trichocarpa*	
		Alnus rubra	*Lithocarpus densiflora*	
		Abies lasiocarpa	*Quercus garryana*	
		Pinus contorta, Acer macrophyllum		

1/ Fast growing, large or long-lived species are at the tops of these columns; slow growing, small or short-lived species are at the bottoms. Species with long growth periods are ranked above those with short periods. Information is insufficient to separate species grouped together.

2/ From Pearson (1924), Haig et al. (1941), Stein (1955, 1963), Tarrant (1953), Boyd (1959), and Ruth (1968a). Rankings were based upon total root length comparisons of equal-age seedlings. Seedling ages varied from 3 months to 2 years.

3/ From Fowells (1941), Buckland (1956), Walters and Soos (1963), Mitchell (1965), and Williams (1968).

4/ From Franklin, Jerry F., and C. T. Dyrness (1973).

these species have not been compared enough with others to permit ranking in table 11.

SHOOT GROWTH PERIOD

In a given locality, some species begin shoot growth earlier in the spring than others. For example, *Pseudotsuga menziesii* breaks bud before *Quercus garryana* in the Willamette Valley of western Oregon (Thilenius 1964), and low-elevation *P. menziesii* trees begin growing several days ahead of associated *Abies grandis* trees in northeastern Oregon (Wickman 1976). Shoot growth initiation dates are extremely variable, however, both within and among species.

Relative growing season lengths apparently are more constant when species are compared...long-season species tend to have longer growing periods than short-season ones whenever they are grown together. Fowells (1941) measured the height growth periods of six northwestern species for 8 years in the Sierra Nevada of California. *Libocedrus decurrens* had the longest growing season, followed by *Pinus ponderosa* and *P. jeffreyi*, *P. contorta*, *Abies concolor*, and *Pinus lambertiana*.

Thuja plicata shoots grow for a longer period than those of *Pinus contorta*, and *P. contorta* has a longer growing season than *Tsuga heterophylla* in the Cascade Mountains of Oregon (Williams 1968). Williams observed that *Tsuga heterophylla*'s growing season exceeded those of *Abies lasiocarpa*, *A. procera*, *A. amabilis*, *Tsuga mertensiana*, and *Pseudotsuga menziesii*. Similar observations were made by Walters and Soos (1963) in southwestern British Columbia. Like Williams, they found that *Thuja plicata* had the longest growing season. *Tsuga heterophylla* had a longer season than *Pseudotsuga menziesii*, which grew for a longer period than *Pinus monticola*. Buckland (1956), also working in southwestern British Columbia, noted that *Pseudotsuga menziesii* and *Abies grandis* ceased shoot growth earlier and more abruptly than *Tsuga heterophylla* and *Thuja plicata*.

Perhaps the most extensive study of shoot growth periods was accomplished by Mitchell (1965), in England. He compared 25 conifer species for four to six seasons. *Thuja plicata* led the northwestern species for a mean length of growing season, followed in order by *Chamaecyparis lawsoniana*, *Tsuga heterophylla*, *Picea sitchensis*, *P. glauca*, *Sequoia sempervirens*, *Pinus contorta*, *Abies grandis*, *Pseudotsuga menziesii*, *Abies procera*, *A. amabilis* and *A. concolor*.

RADIAL GROWTH PERIOD

Godman and Gregory (1953) found that the radial growth of *Picea sitchensis* near Juneau, Alaska occurred over a longer period than that of *Tsuga heterophylla*. This longer radial growth period may contribute to the greater size of *P. sitchensis*, but similar growth period-tree size relationships are not consistently evident among other species. Although the radial growth period of *Alnus rubra* is shorter than the growth periods of the larger *Pseudotsuga menziesii* and *Thuja plicata* (Reukema 1965), the radial growth period of *Abies concolor* is significantly shorter than growth periods of the smaller *Pinus ponderosa* and *Libocedrus decurrens* (Fowells 1941)...and *Sequoia sempervirens* begins growth later than *Abies concolor* in northern California (Bawcom et al. 1961). Growth rate probably is more important than length of growth period in determining mature tree sizes. Sometimes these growth rates are somewhat erratic. While comparing the radial growth of *Abies grandis*, *Larix occidentalis*, *Pinus ponderosa*, and *Thuja plicata* in northern Idaho, Daubenmire (1946) recorded a second September growth spurt. This second spurt occurred only in *Thuja plicata* at low elevations, however, and Daubenmire's radial growth observations may have been affected by the shrinkage associated with drought-caused dehydration.

REPRODUCTION

VEGETATIVE REPRODUCTION

Unlike all other northwestern conifers, *Sequoia sempervirens* reproduces vegetatively by producing vigorous stump sprouts (Harlow and Harrar 1950). *Picea sitchensis*, *Tsuga heterophylla*, and *T. mertensiana* occasionally reproduce by branch-layering (Cooper 1931). *Thuja plicata*, *Chamaecyparis nootkatensis*, *Picea mariana*, *Larix laricina*, and *Abies lasiocarpa* also reproduce vegetatively by developing adventitious roots on low-hanging limbs, broken-off branches, and fallen live boles (Hustich 1953, Schmidt 1955). This vegetative regeneration is as important as reproduction from seed in high density *Thuja plicata* forests (Schmidt 1955), but it seldom occurs in *Abies lasiocarpa* (Cooper 1911). Although northwestern hardwood species (*Alnus rubra*, *Acer* spp., *Quercus* spp. etc.) also develop adventitious roots and stump sprouts, reproduction of northwestern tree species usually involves the production, dissemination, and germination of seeds.

SEED PRODUCTION

Seed production begins at younger ages in some species than in others. The species ranking in table 12 illustrates this in a general way. More detailed comparisons are available for several of these species, but they are difficult to include in an overall comparison. For example, *Abies lasiocarpa* begins to bear seed earlier in life than *Picea engelmannii* (Le Barron and Jemison 1953), but additional information that would relate these species to others in table 12 is lacking.

Additional reproductive differences become evident when seed producing trees of different species are compared. Some develop strobili earlier than others in the spring, and seed dissemination does not occur simultaneously in the fall (table 12). Studying the effects of elevation and climatic factors on production and dispersal of coniferous tree pollen on Vancouver Island, Ebell and Schmidt (1959) found that anthesis occurred first in *Thuja plicata* and *Chamaecyparis nootkatensis*, last in *Tsuga mertensiana*. *Pseudotsuga menziesii* and *T. heterophylla* produced pollen earlier than the *Abies* species on Vancouver Island. Pollen production for *Abies amabilis*, *A. grandis*, and *A. lasiocarpa* occurs somewhat earlier than for *A. procera* in the Cascades (Franklin and Ritchie 1970).

SEED DISSEMINATION

Seed dissemination occurs during a period of several months for most species. Nevertheless, northwestern species differ rather conspicuously when intial seed dissemination dates, rates, and peak periods are compared. *Picea sitchensis* seeds mature earlier than *Tsuga heterophylla* seeds in southeastern Alaska (Harris 1969).

In the somewhat similar environments of western British Columbia, *Abies grandis* and *A. amabilis* seedfalls begin before the seedfall of *Thuja plicata* (British Columbia Forest Service 1950, Garman 1951, 1955, and Hetherington 1965). Then *Thuja plicata*, *Pseudotsuga menziesii*, and *Tsuga heterophylla* begin to drop their seeds, with *P. menziesii* slightly ahead of *T. plicata*, and *T. heterophylla* beginning last (British Columbia Forest Service 1950). *Abies grandis* seed dispersal is completed first, followed by almost all of the *Thuja plicata* seeds, then *P. menziesii*, and finally *T. heterophylla* (British Columbia Forest Service 1950, Garman 1951, 1955). A few *Thuja plicata* seeds must remain in the cones for many months, however, for Pickford (1929) observed *T. plicata* seedfall in July and August of the year following initial seed dissemination.

Farther south, *Abies amabilis* seedfall precedes that of *A. procera* in the Cascade Range (Franklin and Ritchie 1970). *Pinus monticola* seed dissemination occurs before that of *Abies grandis* in the western white pine type, and *A. grandis* seedfall is followed by *Larix occidentalis* and *P. menziesii*. The last species to disseminate seed in the western white pine type are *Thuja plicata* and *Tsuga heterophylla*

Table 12--Comparisons of minimum seed bearing ages, anthesis order, and initial seed dissemination times of northwestern tree species[1]

Minimum seed bearing ages[2]	Anthesis[3]	Initial seed dissemination[4]
Arbutus menziesii	*Thuja plicata, Chamaecyparis nootkatensis*	*Populus tremuloides, Populus trichocarpa*
Pinus contorta	*Pseudotsuga menziesii*	*Pinus monticola, P. lambertiana, P. ponderosa*
Pinus jeffreyi, Alnus rubra, Pseudotsuga menziesii var. *menziesii, Sequoia sempervirens, Acer macrophyllum, Populus trichocarpa*	*Tsuga heterophylla*	*Abies grandis, A. amabilis*
Abies procera, Pinus ponderosa, Pinus monticola, Chamaecyparis lawsoniana, Populus tremuloides	*Abies grandis*	*Pseudotsuga menziesii, Abies concolor, Larix occidentalis, Libocedrus decurrens, Pinus contorta, P. jeffreyi, Picea engelmannii, Chamaecyparis lawsoniana*
Thuja plicata, Picea sitchensis, Abies grandis, Pseudotsuga menziesii var.*glauca*	*Abies amabilis*	*Abies magnifica* var. *shastensis, Thuja plicata*
Tsuga heterophylla, T. mertensiana, Larix occidentalis, Pinus albicaulis	*Pinus contorta*	*Abies lasiocarpa, A. procera, Picea sitchensis*
Larix lyalli, Abies amabilis	*Pinus monticola*	*Chamaecyparis nootkatensis, Tsuga heterophylla*
Quercus kelloggii, Picea glauca	*Abies lasiocarpa*	
Abies magnifica, A. magnifica var. *shastensis, A. concolor*	*Abies procera, Tsuga mertensiana*	
Pinus lambertiana		

[1] The species are ranked from youngest and earliest (top) to oldest and latest (bottom). Where species are absent or occur in the same group, information is insufficient to include or separate them.

[2] Compiled from information obtained from For. Serv. Agric. Handb. No. 450 (1974).

[3] Compiled from the data of Ebell and Schmidt (1959) and Franklin and Ritchie (1970).

[4] Compiled from information published by Pickford (1929), Haig et al. (1941), British Columbia For. Serv. (1950), Garman (1951, 1955), Hetherington (1965), Gashwiler (1969), Harris (1969), Franklin and Ritchie (1970), For. Serv. Agric. Handb. No. 450 (1974), and Wang (1974).

(Haig et al. 1941). *Thuja plicata* and *Tsuga heterophylla* seedfall also occur later than that of *P. menziesii* in west-central Oregon (Gashwiler 1969).

Early *Abies amabilis* seed dissemination may be the results of active cone disintegration--scales literally tear themselves off the cone axis as they distort in drying. *A. grandis* and *A. lasiocarpa* cones also disintegrate, but less actively; *A. procera* cones remain intact until wind action or branch movement disturbs them (Franklin and Ritchie 1970). No obvious cone structure or modification seems to be responsible; but *Tsuga heterophylla* releases seed more slowly than most northwestern trees, regardless of location (Haig et al. 1941, British Columbia Forest Service 1950, Garman 1951 and 1955, Hetherington 1965, Gashwiler 1969, and Harris 1969).

SEED CROP SIZE

Quantity of seeds produced in a seed crop probably is more important than when those seeds are disseminated. Unfortunately, seed crop sizes vary with seasons as well as with species. As a result, observers comparing species in different years often rank species differently. Seed production also varies with locations and with tree age to further complicate species comparisons. For example, Gregory (1957, 1958, 1959) and Harris (1960, 1962) recorded larger average cone crops for *Picea sitchensis* than for *Tsuga heterophylla* during most years in Alaska. In contrast, Ruth and Berntsen (1955) found that *T. heterophylla* "...was a more prolific seed producer..." than *P. sitchensis* in coastal Oregon. Similar observer differences occur with other species. They were reconciled whenever possible in constructing table 13. Where reconciliation was unnecessary (e.g.,

Table 13--Comparative seed crop sizes and frequencies of northwestern tree species[1/]

Seed crop size[2/]	Seed crop frequency[3/]
Thuja plicata, Tsuga heterophylla, Chamaecyparis nootkatensis, C. lawsoniana, Picea sitchensis, Larix occidentalis	*Acer macrophyllum, A. negundo, Populus trichocarpa*
	Pinus monticola, P. contorta
Pseudotsuga menziesii, Pinus contorta, P. jeffreyi	*Tsuga mertensiana, T. heterophylla, Abies lasiocarpa, A. grandis, A. amabilis, Picea engelmannii, Thuja plicata*
Pinus ponderosa	
Pinus lambertiana	*Pseudotsuga menziesii, Larix occidentalis*
Abies concolor	
	Pinus ponderosa, Picea mariana, Populus tremuloides
Abies magnifica	

[1/]Species with the largest or most frequent seed crops are at the top, those with smallest or least frequent crops are at the bottom. Where species are omitted or occur in the same group, information is insufficient to include or separate them.

[2/]Compiled from information published by Boe (1953), Garman (1955), Fowells and Schubert (1956), Gashwiler (1969), Gordon (1970), and Zobel (see footnote 2, page 5).

[3/]Compiled from information published by Boe (1954), Franklin (1968), Franklin et al. (1974), Wang (1974), and Dahms and Barrett (1975).

Garman 1955, Gashwiler 1969), species were ranked without further comment. Where reconciliation was impractical or where sufficient information was lacking, species were discussed, but not included in table 13.

Sequoia sempervirens is a prolific seed producer. Its seed crops are larger than those of *Pinus ponderosa* (Schubert and Adams 1971). Comparing trees of similar size in northern California, Fowells and Schubert (1956) found that *Pinus ponderosa* produced more cones than *P. lambertiana*. When large trees were compared, both *Pinus* species had more cones than *Abies concolor*. Nevertheless, *Abies concolor* produces more sound seeds than *A. magnifica* (Gordon 1970). Schubert and Adams (1971) ranked *Libocedrus decurrens* last in seed production, below *A. magnifica*.

Comparisons with other species are lacking, but Dobbs (1972) found seed production in *Picea glauca* stands to be much higher than production in *P. engelmannii* stands in interior British Columbia. Southward, in northwestern Montana, Boe (1953) counted many more *Larix occidentalis* seeds than *Pseudotsuga menziesii* seeds at the edge of a mixed *Larix-Pseudotsuga* stand. Unfortunately, such stand comparisons are affected by the number of trees in each species that make up the stand. Zobel[4] calculated numbers of seeds per square meter of basal area for each species in his sample stands. Measuring seed crops for 2 seed years, he found *Tsuga heterophylla* to be a better seed producer than *Chamaecyparis lawsoniana*, which produced more seeds than either *Abies concolor* or *Pseudotsuga menziesii* when compared on a basal area basis. When Franklin et al. (1974) compared upper slope species with respect to the number of seeds produced per tree over a 12-year period, they ranked them as follows:

Abies procera (most seeds)
Picea engelmanni
Tsuga mertensiana
Abies grandis, A. concolor
Abies amabilis
Abies magnifica var. *shastensis*
Pinus monticola (fewest seeds).

SEED CROP FREQUENCY

Although seasonal and location variation probably account for most of the differences in relative seed quantitites recorded by different observers for the same species, variation in seed crop frequency (table 13) also must have affected their data and conclusions. Some species, *Pinus monticola* (Franklin 1968, Franklin et al. 1974) for example, produce seeds quite regularly. Others, like *Thuja plicata* (Gashwiler 1969), are erratic and produce a large crop one year and no crop at all for the next year or two.

Although most species seem to be rather intermediate with respect to seed crop frequency, *Tsuga heterophylla* tends to be more frequent than *Picea sitchensis* (Meyer 1937). In Montana, *Pinus contorta* seed crops are more frequent than *Larix occidentalis* crops, which are more frequent than those of *P. ponderosa* (Boe 1954). *Pinus contorta* seed crops also are more frequent than *P. ponderosa* crops in Oregon (Dahms and Barrett 1975). In interior British Columbia, where *Picea engelmannii* and *P. glauca* hybridize, good *P. engelmannii* seed crops are more frequent than good *P. glauca* crops (Dobbs 1972). Wang (1974) published a general summary of seed crop frequencies for 21 northwestern tree species.

SEED SOUNDNESS

Efficacy of any seed crop, regardless of its frequency, is dependent upon sound seeds in that crop. Few species comparisons are available; but *Pinus lambertiana*, *P. ponderosa*, and *Libocedrus decurrens* seed crops have higher proportions of sound seed than *Abies concolor* crops (Fowells and

[4]Zobel, Donald B. Seed production in forests of *Chamaecyparis lawsoniana*. Unpublished manuscript.

Schubert 1956). Gashwiler (1969) found more filled seed in *Thuja plicata* than in *Tsuga heterophylla* or *Pseudotsuga menziesii* during the 12 years he monitored seed fall in west-central Oregon.

SEED FLIGHT

Several important characteristics of seed fall (speed and dispersal distance, for example) are functions of seed weight and structure. Average seed weights of northwestern species are listed in table 14. Seed structures vary greatly. Rather than comparing them as such, several investigators have measured seed flight to compare species seed distribution directly.

Siggins (1933) seems to have done the definitive work in seed flight measurements. After dropping seeds of 13 western conifers down an elevator shaft in the campanile, University of California, Berkeley, he concluded that *Tsuga heterophylla* seeds fell the slowest, *Pinus lambertiana* seeds the fastest. In a less-precise experiment, Isaac (1930) released seeds from a box kite and a pilot balloon under varying wind conditions. He measured the flights of *Tsuga heterophylla*, *Pinus monticola*, *Pseudotsuga menziesii*, *Abies procera*, *Thuja plicata*, and *Pinus ponderosa* seeds over snow covered fields and found them to be in the order given--*Tsuga heterophylla* seeds flying farthest, *Thuja plicata* and *Pinus ponderosa* seeds landing closest to the release point. Pickford (1929) and Gashwiler (1969) also concluded that *Tsuga heterophylla* seeds fly farther than *Thuja plicata* seeds.

In British Columbia and southeastern Alaska, *Tsuga heterophylla* seed flights may be shorter than the flights of *Thuja plicata* (Garman 1951) or *Picea sitchensis* (Godman 1953b) seeds. These northern conclusions were based upon indirect observations rather than direct measurements, however, and unequal consumption by animals or different tree heights and densities may have influenced the seed numbers counted on the ground.

Using seed trap transects extending outward from clearcut edges, Carkin et al. (1978) found that *Abies procera* seed fall declined more rapidly than that of *A. amabilis* in the Washington and Oregon Cascade Range. *Picea engelmannii* seeds fly further than *P. glauca* seeds (Dobbs 1972). Other comparisons are summarized in table 14.

SEED DURABILITY AND LONGEVITY

Both long and short seed flights separate seeds from their parent cones and expose them to environmental stresses that must be endured until germination is accomplished. *Pinus monticola* (Hofmann 1925), *P. contorta*, and *P. ponderosa* (Wright 1931) seeds are more resistant to high temperatures than *Pseudotsuga menziesii* seeds. When seeds are stored for long periods under cooler temperature conditions, the *Pinus* species again seem to be more resistant and long-lived (Isaac 1940 and 1943, Schubert 1954, Holmes and Buszewicz 1958). Other species longevity comparisons are summarized in table 15.

SEED GERMINATION

Given similar environmental conditions, *Pseudotsuga menziesii* seeds usually are easier to germinate than *Pinus monticola* or *P. lambertiana* seeds (Allen and Bientjes 1954). Similar differences have been noted by other workers, using other species. For example, Dobbs (1972) found *Picea engelmannii* seeds to have "...on the average, higher germinative energy and higher germinative capacity..." than *P. glauca* seeds. Germination rates and stratification requirements are compared in table 16.

Species germination rates have been compared more than other germination attributes. *Abies procera* seeds germinated faster than *A. magnifica* var. *shastensis* seeds when covered with 1/2 inch (1.3 cm) of mineral soil, and both of these *Abies* species germinated before adjacent *Pinus*

Table 14--Comparative seed weights and seed flight distances of northwestern tree species

Seed weights[1]	Seed flight distances[2]
Populus tremuloides	*Tsuga heterophylla*
[illegible]	*Pinus contorta*
[illegible]	*Picea sitchensis*
[illegible]	*Pseudotsuga menziesii*
Arbutus menziesii	*Abies amabilis*
Picea glauca	*Pinus ponderosa*
Picea sitchensis, Chamaecyparis lawsoniana	*Thuja plicata*
Larix lyalli	*Abies grandis, A. concolor*
Larix occidentalis	*Libocedrus decurrens*
[illegible]	*Pinus jeffreyi*
Sequoia sempervirens	*Sequoia sempervirens*
Tsuga mertensiana	*Pinus lambertiana*
Chamaecyparis nootkatensis	
Pinus contorta	
Picea breweriana	
Pseudotsuga menziesii	
Abies lasiocarpa	
Pinus monticola	
Abies grandis	
Libocedrus decurrens	
Taxus brevifolia	
Abies procera	
Pinus ponderosa	
Abies concolor, A. amabilis	
Abies magnifica var. *shastensis*	
Abies magnifica	
Pinus jeffreyi, Acer macrophyllum	
Pinus albicaulis, P. lambertiana	
Lithocarpus densiflora, Quercus garryana, Q. kelloggi	

[1] Derived from data published in For. Serv. Agric. Handb. No. 450 (1974). Species with light seeds are listed above those with heavy seeds. Species on the same line have equal seed weights.

[2] Based upon the seedfall measurements of Siggins (1933). Species with long seed flights are listed above those with short flights. Species on the same line have the same flight characteristics. Where species are omitted, data are insufficient for comparison.

monticola seeds in the Cascade Range (Franklin and Hoffman 1968). Further differences are present among both *Abies* and *Pinus* species. Davidson (1959) found *Abies grandis* germination to be faster than that of *A. amabilis*, and Lanquist (1946) observed faster germination in *A. concolor* than in *A. magnifica*. Lanquist's data also showed that *Pinus jeffreyi* seeds germinated faster than those of *P. ponderosa*, which were far ahead of *P. lambertiana* seeds. His data show *Abies concolor* to germinate slightly faster than *Libocedrus decurrens*--a finding that conflicts with an earlier statement by Show (1930) attributing greater rapidity to the *L. decurrens* germination. As Lanquist sowed the *Abies* and *Libocedrus* seeds at different depths, Show's statment probably is correct. *Pseudotsuga menziesii*

Table 15--Comparative seed longevity of northwestern tree species[1]

Pinus ponderosa
Pinus contorta
Pinus jeffreyi
Pinus lambertiana
Pinus monticola
Pseudotsuga menziesii, Thuja plicata, Chamaecyparis lawsoniana, Tsuga heterophylla, Picea sitchensis
Larix occidentalis
Pinus albicaulis
Abies procera, Tsuga mertensiana, Picea engelmannii
Abies concolor, A. grandis, A. lasiocarpa, A. magnifica, Libocedrus decurrens, Sequoia sempervirens

1/Compiled from data published by Schubert (1954) and Holmes and Buszewicz (1958). Species with more longevity are listed above those with less. Information is insufficient to separate species listed in the same group.

Table 16--Comparative germination attributes of northwestern tree species[1]

Germination rate[2]	Stratification required[3]
Pinus jeffreyi, P. ponderosa, Abies procera	*Picea sitchensis, P. engelmannii, P. glauca, Thuja plicata, Chamaecyparis lawsoniana, Tsuga heterophylla, Pinus ponderosa, P. jeffreyi*
Pseudotsuga menziesii, Abies grandis, A. concolor, A. magnifica var. *shastensis, Libocedrus decurrens*	*Abies magnifica* var. *shastensis, A. grandis, A. concolor, A. procera, A. lasiocarpa, A. amabilis, Pseudotsoga menziesii, Pinus contorta*
Pinus lambertiana, P. monticola, Picea engelmannii	*Pinus lambertiana, P. monticola, Acer* species, *Taxus brevifolia*

1/Species germinating faster and those requiring less stratification are listed above slower, stratification-dependent species. Where species occur in the same group, information is insufficient for further separation.

2/From Lanquist (1946), Murison (1959), Stein (1963), and Franklin and Hoffman (1968).

3/From Heit (1968), Kotar (1972), and For. Serv. Agric. Handb. No. 450 (1974).

germination is slower than that of *Pinus ponderosa* (Lanquist 1946, Murison 1959), faster than that of *Tsuga heterophylla* (Gashwiler 1969) or *Pinus lambertiana* (Lanquist 1946, Murison 1959, Stein 1963). Murison (1959) found *Pinus ponderosa* seed germination to be faster than *Pseudotsuga menziesii* var. *glauca*, which was faster than *P. menziesii*

var. *menziesii*. Both *Pseudotsuga* varieties germinated faster than *Pinus lambertiana* after a 6-week stratification period. The earliest germination of Murison's stratified *Picea engelmannii* seeds occurred slightly later than that of his stratified *Pinus monticola*.

SEED STRATIFICATION REQUIREMENTS

Seed stratification is essential for the prompt germination of some northwestern tree species, unnecessary for others. Stratification requirements appear to be highest for *Pinus lambertiana*, *P. monticola*, *Taxus brevifolia*, and *Acer* species. *Abies grandis*, *A. procera*, *Pseudotsuga menziesii*, *Picea breweriana*, and stored *Pinus ponderosa* seeds also benefit from a moist, cool pregermination treatment; but *Thuja plicata*, *Picea engelmannii*, *P. sitchensis*, and fresh *Pinus ponderosa* seeds do not require prechilling (Heit 1968, Forest Service, USDA 1974). Although *Abies amabilis* germination occurs faster after stratification for 8 weeks at 4°C, *Tsuga heterophylla* germination is retarded by this treatment (Kotar 1972).

GERMINATION ENVIRONMENTS

Soil attributes have been related to the germination of several northwestern tree species. *Thuja plicata* germination is best in alkaline soil; but *Tsuga heterophylla* germination is depressed there, reaching is optimum under acid conditions (Thrupp 1939). Thrupp, working under poorly controlled greenhouse conditions, concluded that magnesium retards *Picea sitchensis* and *Thuja plicata* germination but accelerates the germination of *Pseudotsuga menziesii* and *Tsuga heterophylla*. The germination of *P. menziesii* is not as sensitive to soil moisture stress as that of *Picea engelmannii* (Brayshaw 1970). Soil moisture may have influenced the results published by Garman (1955). He noted that maximum germination of *Tsuga heterophylla*, *Picea sitchensis*, and *Thuja plicata* occurred in 75-percent shade, whereas maximum *Pseudotsuga menziesii* germination occurred in only 25-percent shade. Moisture's importance certainly was demonstrated by Ackerman (1957), who sowed *Picea glauca* and *Pinus contorta* seeds on both trenched and untrenched seedbeds in Alberta. Where the trenching removed root competition of the residual stand, *P. contorta* germination and survival were benefited but *P. glauca* was not affected.

SEEDBEDS

Seed germination and subsequent seedling survival are greatly affected by seedbed conditions. Although good seedbeds (e.g., mineral soil) tend to be favorable for all northwestern tree species, some species apparently are able to utilize good seedbeds more efficiently than others. Conversely, some species are able to tolerate poor seedbeds better than others. These general seedbed-species relationships are shown for several northwestern trees in table 17.

Lack of available moisture probably contributes to the poor seedbed characteristics of moss, litter, and duff. Surface moss dries out rapidly. *Tsuga heterophylla* seeds apparently germinate better than *Thuja plicata* or *Picea sitchensis* seeds in this moss (Godman 1953a, Phelps 1973)...and the *T. plicata* survival is better than that of either *Tsuga* or *Picea* in southeastern Alaska (Godman 1953a).

Moisture associated with shaded conditions probably influenced the germination and survival of Sierra Nevada conifers on the seedbeds subjectively compared by Stark (1965). Stark concluded that *Libocedrus decurrens* germinated best on bare soil in half shade, but *Pinus lambertiana* germination was best on light litter in full sunlight. Survival of both species was judged to be highest where litter occurred.

In greenhouse and laboratory studies, seedbed differences persist even when moisture differences are minimized. An ash seedbed stimulated *Pseudotsuga menziesii* germination but reduced the germination of *Tsuga heterophylla* and *Thuja plicata* when Jablanczy (1963) compared ash

Table 17--Comparative seedbed suitability of northwestern tree species[1/]

Organic seedbeds		Mineral soil seedbeds		Burned seedbeds
Coastal	Interior	Coastal	Interior	
Tsuga heterophylla	*Picea glauca, Pseudotsuga menziesii*	*Alnus rubra*	*Larix occidentalis, Picea engelmannii*	*Pseudotsuga menziesii, Abies grandis, Pinus ponderosa*
Thuja plicata	*Abies lasiocarpa, Pinus contorta*	*Picea sitchensis*	*Pinus contorta, Abies lasiocarpa*	*Tsuga heterophylla, Larix occidentalis, Picea engelmannii, Pinus contorta*
Picea sitchensis	*Larix occidentalis, Picea engelmannii*	*Thuja plicata*	*Pseudotsuga menziesii, Picea glauca*	*Thuja plicata, Pinus monticola, Abies lasiocarpa*
Alnus rubra		*Tsuga heterophylla*		

1/ Compiled from information published by Fisher (1935), Taylor (1935), Godman (1953a), Bever (1954), Muri (1955), Smith (1955), Day (1957), Smith and Clark (1960), Jablanczy (1963), Soos and Walters (1963), Ruth (1968b), Boyd and Deitschman (1969), Schmidt (1969), Phelps (1973), and Ryker (1975). Species in upper groups are better suited to the seedbed than those in the lower groups. Data are insufficient for species comparisons within groups.

and vermiculite substracts in petri dishes. When Fisher (1935) compared germination on various seedbeds, he found that *Pseudotsuga menziesii, Abies grandis,* and *Pinus ponderosa* all germinated best on ash. *Tsuga heterophylla, Thuja plicata,* and *Larix occidentalis* germinated best on virgin *Pinus monticola* duff; but both *Picea engelmannii* and *Pinus contorta* germination were best on rotten wood.

Picea engelmannii duff proved to be lethal when Daniel and Schmidt (1972) stratified *P. engelmannii, Abies lasiocarpa, Pseudotsuga menziesii,* and *Pinus contorta* seeds in it. The lethal effect was eliminated by autoclaving, and it was much less severe when duff from other species was tested--*Pseudotsuga menziesii* and *Abies lasiocarpa* duff seriously affected only *P. menziesii* and *A. lasiocarpa* seeds, respectively; and *Pinus contorta* duff was almost neutral to seeds of all species. Moist *Tsuga heterophylla* duff delayed the germination of *Pseudotsuga menziesii* more than *Picea sitchensis, Pinus contorta, Tsuga heterophylla, Thuja plicata,* and *Abies amabilis* germination (Minore 1972). In a growth chamber experiment, Minore found that *P. menziesii* seedling survival was better on rotten *P. menziesii* wood than on *Tsuga heterophylla* duff but *Alnus rubra* survival was better on the duff. Failure to develop either root hairs or root nodules on the rotten wood probably contributed to *A. rubra*'s poor survival there.

Alnus rubra survival and growth seem to be better on mineral soil than on organic seedbeds. As *Tsuga heterophylla* and *Picea sitchensis* readily germinate and grow on organic seedbeds, reduced disturbance of the forest floor may favor these conifers over *A. rubra* in coastal Oregon and Washington (Ruth 1968b). In coastal Alaska and British Columbia, *Tsuga heterophylla* seems to be better suited to organic seedbeds than either *Picea sitchensis* (Taylor 1935, Day 1957) or *Thuja plicata* (Day 1957).

Farther inland, an undisturbed forest floor favors *Pseudotsuga menziesii* and *Abies lasiocarpa* over *Larix occidentalis* and *Picea engelmannii* but a mineral soil seedbed favors the *Larix* and *Picea* over *P. menziesii, A. lasiocarpa,* and *Pinus contorta* (Schmidt 1969). Although a mineral soil seedbed does not seem to be as critical for *P. menziesii* on some habitats as for other species, such as *Larix occidentalis* in the Rocky Mountains (Ryker 1975), Prochnau (1963) found that preparation of a mineral soil seedbed was essential to good establishment of *Picea glauca, Abies lasiocarpa, Pseudotsuga menziesii* and *Pinus contorta* in the central interior of British Columbia. Where a mineral soil seedbed was not prepared, *A. lasiocarpa* was able to establish itself better than *P. engelmannii* on litter and moss seedbeds (Smith 1955). *A. lasiocarpa* also seemed to be better than a *Picea engelmannii-P. glauca* hybrid in this respect...but the hybrid was more successful on rotten wood (Day 1964). Bulldozer scarification produces a seedbed more favorable for *P. engelmannii* than for *A. lasiocarpa* (Boyd and Deitschmann 1969).

Burned seedbeds also favor *P. engelmannii* over *A. lasiocarpa* (Muri 1955, Smith and Clark 1960). Although unburned mineral soil was more favorable for *Thuja plicata,* burned mineral soil was the best *Tsuga heterophylla* seedbed in British Columbia (Soos and Walters 1963). In central western Oregon, stocking of *Pseudotsuga menziesii* seedlings was better where slash was burned than where it was not. *Tsuga heterophylla* stocking showed no such difference (Bever 1954).

PHYSICAL CHARACTERISTICS

Unfortunately, burned seedbeds often result from fires that burn standing trees as well as slash. Northwestern tree species differ with respect to fire resistance and other physical characteristics. Many of these differences are summarized in table 18.

Anatomical differences among northwestern tree species are evident even in young seedlings. Cotyledon numbers vary, but they range within characteristic limits for most northwestern trees. Franklin (1961) noted these ranges

in his seedling identification guide. *Pinus* species tend to have the most numerous cotyledons. "Cedars" (*Thuja, Chamaecyparis, Libocedrus* spp.) and *Taxus brevifolia* have the fewest.

NEEDLES

Smith (1970) used larger trees in determining needle volumes, weights, and longevity for several northwestern species. His data indicate that *Pinus monticola* needles are less dense than *P. contorta* needles when density is expressed as weight per unit volume. *Pseudotsuga menziesii* and *Picea sitchensis* needles also are less dense than those of *Pinus contorta* when weight-volume relationships are considered. When weight per unit surface area is the parameter being considered, *Pseudotsuga menziesii* is less dense than either *Pinus contorta* (Mellor and Tregunna 1972) or *Picea sitchensis* (Krueger and Ruth 1969). The weight-surface area measurements of Krueger and Ruth indicate that *Tsuga heterophylla* needles are less dense than *Pseudotsuga menziesii* needles, and *Alnus rubra* leaves are even less dense than *T. heterophylla*. Regardless of individual needle densities, *Tsuga heterophylla* and the *Pinus* species tend to lose their needles sooner than the *Picea* and *Abies* species (Smith 1970). Young *Pinus ponderosa* needles have higher levels of photosynthesis than young *Abies concolor* needles, but these levels decline faster with age in *P. ponderosa* (Freeland 1952).

Numbers and distribution of needles probably are as important as individual needle densities and photosynthetic levels in the life of a tree. Northwestern tree species exhibit characteristic differences in this respect, both in needle quantity and in aerial distribution. For example, *Pinus contorta* had 10 times the needle weight of *Picea glauca* and 6 times the needle weight of *Abies lasiocarpa* when 5-year-old seedlings were compared in British Columbia (Eis 1970). When total crown weights (branchwood as well as needles) of older trees are compared, the species rank differently.

CROWNS

Pinus ponderosa had the heaviest crown weight of 11 Rocky Mountain conifers compared by Brown (1976). Chandler (1960) also found *P. ponderosa* crown weight to be the heaviest when he calculated slash dry weights for large trees in the westside mixed conifer forests of California. For small trees, his calculations showed *Pseudotsuga menziesii* and *Abies concolor* crowns to be heavier than those of *P. ponderosa*. The crown weight of *Libocedrus decurrens* was the lightest calculated by Chandler; but *Larix occidentalis* and *Pinus monticola* had the lightest crowns measured by Brown. *Pinus contorta* crowns also are relatively light, and Tackle (1959) observed that *P. contorta* had a greater leaf area per unit of weight than *P. ponderosa*. Hardwood crown weights were not compared with these conifers, but Sundahl (1966) found *Lithocarpus densiflora* crowns to be about three times heavier than the crowns of *Arbutus menziesii* and two times heavier than those of *Quercus kelloggii*.

Species with heavy crowns tend to have larger crowns than species with light crowns, but crown shapes vary almost as much as crown weights. *Picea engelmannii* (Starker 1934, Fahnestock 1960) and *Abies lasiocarpa* (Flint 1925) have the longest crowns. Although Flint, Starker, and Fahnestock all rate *Larix occidentalis* as one of the shortest-crowned species, these authors differ with regard to other species. *Pinus monticola's* branch height is described as similar to that of *Larix occidentalis* ("high") by Flint (1925) and Starker (1934), but Fahnestock (1960) described *P. monticola* crowns as "medium to long" and listed *Larix occidentalis, Pinus ponderosa,* and *Pseudotsuga menziesii* in the "short to medium" crown category. The *P. menziesii* crown was described as being longer than that of *P. ponderosa* by Flint (1925), shorter than *P. ponderosa* by Starker (1934). Differences like these probably were caused by unrecognized environmental and stand density differences among observers. They have been resolved by listing species in the same table 18 group where references conflicted.

Table 18--Comparative physical characteristics

Cotyledon number[2]	Needle longevity[3]	Needle volume[3]	Needle weight[3]	Total crown weight[4]
Pinus lambertiana	*Abies grandis*	*Pinus monticola*	*Pinus contorta*	*Pinus ponderosa*
Pinus jeffreyi	*Picea sitchensis*	*Pinus contorta*	*Pinus monticola*	*Abies grandis, A. concolor, A. lasiocarpa, Pseudotsuga menziesii, Picea engelmannii*
Pinus ponderosa	*Abies amabilis*	*Abies grandis*	*Abies grandis*	*Tsuga heterophylla, Thuja plicata, Pinus contorta, P. albicaulis, P. lambertiana*
Pinus monticola	*Pseudotsuga menziesii*	*Picea sitchensis*	*Picea sitchensis*	*Larix occidentalis, Pinus monticola, Libocedrus decurrens*
Pinus attenuata, Pseudotsuga menziesii, Abies magnifica var. *shastensis, A. concolor*	*Pinus monticola*	*Pseudotsuga menziesii*	*Abies amabilis*	
Picea engelmannii	*Tsuga heterophylla*	*Tsuga heterophylla*	*Pseudotsuga menziesii*	
Abies amabilis, A. grandis, Larix occidentalis, Picea breweriana	*Pinus ponderosa*		*Tsuga heterophylla*	
Pinus contorta	*Pinus contorta*			
Picea sitchensis, Abies procera				
Abies lasiocarpa				
Tsuga mertensiana				
Tsuga heterophylla				
Chamaecyparis nootkatensis, C. lawsoniana, Thuja plicata, Taxus brevifolia, Libocedrus decurrens				

[1] Species in the same group are not necessarily equal, but data are insufficient for species comparisons within groups.

[2] Compiled from data published by Franklin (1961). Species with many cotyledons are listed above those with few.

[3] Based on data published by Smith (1970). Species with the largest, heaviest, and most persistent needles are listed above those with smaller, lighter, and shorter-lived needles.

[4] From Chandler (1960) and Brown (1976). Species with heavy crowns are listed above those with light crowns.

of northwestern tree species[1] (continued)

Crown length[5]	Crown width[6]	Crown density[7]	Annual litter fall[8]	Heartwood specific gravity[9]
Picea engelmannii, Abies lasiocarpa	*Pinus ponderosa, Tsuga heterophylla*	*Pinus albicaulis*	*Thuja plicata*	*Quercus garryana*
Tsuga heterophylla, T. mertensiana, Thuja plicata, Abies grandis, A. concolor	*Thuja plicata*	*Abies lasiocarpa*	*Pseudotsuga menziesii* (350 years old)	*Taxus brevifolia*
Picea sitchensis, Pinus ponderosa, P. contorta, Pseudotsuga menziesii, Abies procera, Pinus monticola	*Pseudotsuga menziesii*	*Picea engelmannii*	*Abies amabilis*	*Larix occidentalis*
Larix occidentalis	*Abies grandis*	*Abies grandis, Tsuga heterophylla, Pseudotsuga menziesii, Pinus ponderosa, P. contorta, P. monticola*	*Acer macrophyllum*	*Fraxinus oregona*
	Picea engelmannii	*Larix occidentalis*	*Pinus monticola*	*Pseudotsuga menziesii* var. *menziesii*
	Pinus monticola, P. contorta, Larix occidentalis	*Thuja plicata*	*Alnus rubra*	*Acer macrophyllum*
			Tsuga heterophylla	*Tsuga mertensiana*
			Pseudotsuga menziesii (100 years old)	*Pseudotsuga menziesii* var. *glauca, Sequoia sempervirens, Chamaecyparis lawsoniana*
			Picea sitchensis	*Tsuga heterophylla, Pinus contorta, P. ponderosa*
			Pinus ponderosa	*Picea sitchensis, P. glauca, Pinus jeffreyi, P. monticola, P. lambertiana, Abies magnifica, A. concolor, A. grandis, A. procera, A. amabilis, Alnus rubra, Populus tremuloides, Libocedrus decurrens*
			Pinus contorta	*Populus trichocarpa, Picea engelmannii, Abies lasiocarpa, Thuja plicata*

[5] From Flint (1925), Starker (1934), and Fahnestock (1960). Species with long crowns are listed above those with shorter crowns.

[6] From Fahnestock (1960). Species with wide crowns are listed above those with narrow crowns.

[7] From Brown's (1978) measurements of foliage plus branchwood bulk densities in dominant trees. Species with dense crowns are listed above those with less-dense crowns.

[8] From Tarrant et al. (1951). The heaviest litter fall is listed at the top, the lightest at the bottom.

[9] Compiled from data published by Markwardt (1931), Markwardt and Wilson (1935), USDA Forest Products Laboratory (1955, 1965), Born (1966), and Farr (1973). Species with high specific gravities are listed above those with low specific gravities.

Table 18--Comparative physical characteristics

Branchwood specific gravity10/	Sapwood thickness11/	Bark thickness12/	Foliage flammability13/	Epiphyte receptivity14/
Pseudotsuga [illegible]	*Pinus ponderosa*	*Larix occidentalis, Pseudotsuga menziesii*	*Picea engelmannii, P. sitchensis, Pseudotsuga menziesii, Thuja plicata, Tsuga heterophylla, T. mertensiana, Abies procera, A. lasiocarpa*	*Alnus rubra*
Pinus contorta	*Pinus contorta*	*Pinus ponderosa*	*Abies grandis, A. concolor, Pinus monticola*	*Picea sitchensis, Abies procera*
Abies grandis, Larix [illegible]	*Pseudotsuga menziesii, Picea engelmannii*	*Abies grandis, A. concolor,* [illegible]	*Pinus contorta*	*Tsuga heterophylla, Picea engelmannii*
	Thuja plicata	*Pinus monticola, Tsuga heterophylla, T. mertensiana*	*Larix occidentalis, Pinus ponderosa*	*Pseudotsuga menziesii, Larix occidentalis*
	Larix occidentalis	*Thuja plicata*		*Pinus monticola*
		Picea sitchensis, P. engelmannii, Pinus contorta, Abies lasiocarpa, Chamaecyparis nootkatensis		*Thuja plicata*
				Populus trichocarpa
				Acer macrophyllum
				Chamaecyparis nootkatensis, Taxus brevifolia
				Abies lasiocarpa
				Abies grandis, A. concolor
				Populus tremuloides
				Pinus contorta
				Quercus garryana
				Arbutus menziesii
				Tsuga mertensiana

10/ From Ryan and Pickford (1978). Species with high specific gravities are listed above those with low specific gravities.

11/ From Lassen and Okkonen (1969). Species with thick sapwood are listed above those with thin sapwood.

12/ Compiled from information published by Flint (1925), Starker (1934), and Bones (1962). Species with thick bark are listed above those with thin bark.

13/ Compiled from information published by Flint (1925) and Starker (1934). Species with highly flammable foliage are listed above those with less flammable foliage.

14/ Compiled from information published by Flint (1925), Starker (1934), Coleman et al. (1956), and Pechanec and Franklin (1968). Species supporting more epiphytes are listed above those supporting less.

of northwestern tree species[1]

Fire resistance[15]		Rooting depth[16]	Windthrow resistance[17]	Growth in dense soils[18]	Snow damage resistance[19]
Coastal	Interior				
Pseudotsuga menziesii	*Larix occidentalis*	*Pinus ponderosa*	*Pseudotsuga menziesii, Thuja plicata*	*Larix occidentalis, Pinus monticola, P. ponderosa, P. lambertiana*	*Tsuga mertensiana, T. heterophylla, Picea breweriana, Abies magnifica* var. *shastensis*
Abies grandis, A. concolor	*Pinus ponderosa, Pseudotsuga menziesii*	*Pinus lambertiana, Libocedrus decurrens*	*Picea sitchensis*	*Pseudotsuga menziesii, Pinus contorta*	*Pinus monticola, Abies amabilis*
Tsuga mertensiana	*Pinus lambertiana, Abies grandis, A. concolor*	*Pseudotsuga menziesii, Abies grandis, Pinus monticola, Larix occidentalis*	*Tsuga heterophylla*	*Abies amabilis*	*Abies procera, A. concolor, Pinus jeffreyi*
Abies procera	*Libocedrus decurrens, Pinus monticola, Thuja plicata, Tsuga mertensiana*	*Thuja plicata*	*Abies amabilis*	*Picea sitchensis, Tsuga heterophylla, Thuja plicata*	*Pseudotsuga menziesii, Pinus lambertiana, P. ponderosa*
Pinus monticola	*Pinus contorta, Picea engelmannii, Tsuga heterophylla*	*Tsuga heterophylla*			
Pinus contorta	*Abies lasiocarpa*				
Tsuga heterophylla					
Picea sitchensis, Thuja plicata					

[15] Based upon observations by Kerr (1913), Flint (1925), Starker (1934), Boyd (1959), Tackle (1959), and Wallis et al. (1974). Fire resistant species are listed above less resistant species.

[16] From Haig (1936) and Stein (1963). Deep-rooted species are listed above shallow-rooted species.

[17] From Boyce (1929), Ruth and Yoder (1953), and Gratkowski (1956). Resistant species are listed above non-resistant species.

[18] From Leaphart (1958), Stephens (1965), and Minore et al. (1969). Species capable of growing in dense soils are listed above those that are not.

[19] From Williams (1966), Kangur (1973), and Waring et al. (1975). Resistant species are listed above non-resistant species.

Conflicting references are not a problem with crown widths and crown densities, for there seem to be very few sources of this information. Fahnestock (1960) described *Pinus ponderosa* and *Tsuga heterophylla* crowns as "wide;" *Pinus monticola, P. contorta,* and *Larix occidentalis* crowns as "narrow." His intermediate descriptions were used in ranking crown widths in table 18. Brown's (1978) measurements of foliage and branchwood bulk densities were used in ranking crown densities. Although he did not rank species in terms of crown width or density, Gratkowski (1956) noted that *Thuja plicata* crowns were less dense than the crowns of *Tsuga heterophylla* and *Abies amabilis*. Fahnestock (1960) observed that the quantity of foliage plus very fine twigs in individual crowns seems to be related to species shade tolerance--the higher the percentage of total crown weight in foliage, the more tolerant is the species.

LITTER FALL

Large, dense crowns do not necessarily produce large quantities of litter. When Tarrant et al. (1951) measured the annual litter fall in pure, well-stocked stands of 10 northwestern tree species, they found that *Thuja plicata* (a species with moderate crown size and density) produced the most litter. A 350-year-old stand of *Pseudotsuga menziesii* dropped more than twice as much litter as a 100-year-old stand, and age differences may have influenced the data published by Tarrant et al. Nevertheless, their general comparison emphasizes the large differences between species...*Thuja plicata* produced almost eight times as much litter as *Pinus contorta*.

WOOD

Although they may not vary annually like litter fall, wood properties of the various species are not at all constant. They vary with latitude, age, and position in the tree. Nevertheless, differences in wood characteristics among species are of great importance and have been studied extensively. Most of these studies will not be reviewed here. Only two wood properties have been selected for comparison--heartwood specific gravity and sapwood thickness.

Specific gravity values were compared to obtain the species ranking shown in table 18. Not shown are species differences in the way wood specific gravity changes with height in the tree. Okkonen et al. (1972) found that specific gravity decreased as height increased in *Pseudotsuga menziesii, Pinus ponderosa, Larix occidentalis, Abies grandis, A. procera, A. magnifica,* and *A. amabilis*. It increased with height in *Thuja plicata, Populus trichocarpa,* and *Picea engelmannii*. The specific gravity of *Abies concolor* initially decreased, then increased farther up the tree. Progressing outward from pith to bark, tracheid length tends to increase in all conifers--but Anderson's (1951) four-tree sample indicated that this increase is greater in *Pseudotsuga menziesii* than in *Abies concolor* or *A. procera*.

Sapwood thickness increases with increasing tree diameter in western softwoods (Lassen and Okkonen 1969). When Grier and Waring (1974) compared sapwood cross sectional area and foliage mass, they found them to be highly correlated. Furthermore, the correlations varied consistently among the three species investigated. *Pseudotsuga menziesii* had more foliage per unit sapwood than either *Abies procera* or *Pinus ponderosa*. In small trees, *P. ponderosa* had more foliage per unit sapwood than *A. procera*, but in large trees *A. procera* had more foliage for its sapwood than *P. ponderosa*.

The pattern of water conduction in sapwood and heartwood differs among northwestern conifers. It occurs in an ascending right spiral in *Pinus contorta, P. ponderosa, P. jeffreyi, Larix* species, *Picea* species, and *Abies* species (Rudinsky and Vite' 1959). In *Pinus monticola* and *P. lambertiana*, conduction occurs in an ascending left spiral. Rudinsky and Vite' discovered an interlocking zigzag

ascent in *Libocedrus decurrens*, *Sequoia sempervirens*, and *Juniperus* species. In *Pseudotsuga menziesii* and *Tsuga* species, the ascent of water is neither in a complete spiral nor along an interlocking pathway--it winds around the stem in a coherent section. The coherent section does not wind in *Thuja plicata* and *Chamaecyparis lawsoniana*, but goes straight up the tree. Pattern of water conduction probably influences sapwood permeability. *Pseudotsuga menziesii* sapwood is less permeable than that of *Pinus contorta* or *Picea engelmannii* (Markstrom and Hann 1972). In contrast, heartwood permeability to liquids is higher in *P. engelmannii* and *P. menziesii* than in *P. contorta*; permeability to gases is higher in *P. contorta*.

BARK

Bark characteristics are more easily seen and compared than most physical attributes. As a result, bark traits tend to be general knowledge, and only a few comparisons of bark thickness have been published. These are very similar, ranking in the order shown in table 18. As the comparative bark thicknesses indicate, total bark content of the tree is higher for *Pseudotsuga menziesii* than for either *Tsuga heterophylla* or *Thuja plicata* (Smith, Kerr, and Czizmazia 1961). Relatively thin bark and a long cylindrical bole give *Abies procera* a greater volume for its diameter at breast height than associated species, with the possible exception of *Pinus monticola* (Hanzlik 1925).

Resin content of old bark was characterized in general terms by Flint (1925). *Pinus ponderosa*, *P. contorta*, and *P. monticola* barks have the most resin; *Larix occidentalis*, *Abies grandis*, *Tsuga heterophylla*, *T. mertensiana*, and *Thuja plicata* barks have the least. Flint rated *Pseudotsuga menziesii*, *Picea engelmannii*, and *Abies lasiocarpa* as intermediate in bark resin content.

SLASH

Bark resin content is an important determinant of fire intensity. So are the slash characteristics and foliage inflammability of northwestern tree species. Foulger et al. (1976) analyzed western softwood logging residues less than .25 inch (.64 cm) in diameter for bark, needle, and solid wood content. They found that *Larix occidentalis* had the highest proportion of solid wood, followed by *Pinus contorta*, *Pseudo-* [illegible] *lasiocarpa*, *Pinus ponderosa*, and *Picea engelmannii*. Moisture content of the solid wood component of slash also may differ in different species, sometimes in unexpected ways. Scott (1964) found that moisture distribution in large-diameter *Pseudotsuga menziesii* slash was radial, with moisture content increasing from 6 in (15 cm) inside the log out to its surface. The moisture distribution in large *Lithocarpus densiflora* slash on the same clearcut was just the opposite, however, with moisture content decreasing from inside out.

Moisture distribution, branch size, and needle retention all effect the flammability of slash. Olson (1953) made some preliminary tests of slash flammability in the western white pine type. He concluded that fire spread rates were highest in *Larix occidentalis* slash until it lost its needles, followed by *Tsuga heterophylla*, *Pseudotsuga menziesii*, *Pinus monticola*, *Abies grandis*, *Pinus contorta*, *Thuja plicata*, *Picea engelmannii*, and *Pinus ponderosa*. Although it had the slowest spread rate, *P. ponderosa* had the hottest-burning slash. Fahnestock (1960) tested slash quality more extensively. He suggested the following spread-rate rankings:

<u>Fresh Slash</u>

Larix occidentalis (fastest spread)

Pinus monticola, *Thuja plicata*, *Pseudotsuga menziesii*, *Tsuga heterophylla*, and *Abies grandis* (intermediate spread)

Pinus ponderosa and *Picea engelmannii* (slowest spread)

One-year-old Slash

Pinus monticola, P. contorta, Thuja plicata (fastest spread)

Pinus ponderosa, Pseudotsuga menziesii, Tsuga heterophylla, and *Picea engelmannii* (intermediate spread)

Abies grandis and *Larix occidentalis* (slowest spread)

Fahnestock found needle moisture content in fresh slash to be highest in *Larix occidentalis,* lowest in *Pseudotsuga menziesii.* Branchwood moisture in freshly cut slash was highest in *Pinus contorta,* lowest in *Larix occidentalis.*

MOISTURE CONTENT

Moisture content apparently differs in standing trees as well as in slash. Parker (1954) measured more heartwood moisture and total trunk water content in *Pinus ponderosa* and *Abies grandis* than in *Pseudotsuga menziesii* or *Thuja plicata.* When he compared twig moisture content with the foliage weight attached to those twigs, he found that *Pinus ponderosa* also had far more water per unit foliage than *Abies grandis, Pseudotsuga menziesii,* or *Thuja plicata.* The seasonal fluctuation of foliage moisture content was studied by Pharis (1967), who noted that the summer moisture content of new foliage was higher in *Pinus ponderosa* and *P. lambertiana* than in *Pseudotsuga menziesii.* Foliage moisture content declined between November and February in *P. menziesii* and *Abies grandis*, but not in *P. lambertiana, P. ponderosa,* or *Libocedrus decurrens.*

FOLIAGE FLAMMABILITY AND EPIPHYTE RECEPTIVITY

Foliage moisture probably influences foliage flammability, a factor rated by Flint (1925) in the northern Rocky Mountains and by Starker (1934) in Oregon and Washington. As their species comparisons were quite similar, they were combined in table 18 with only minor modification. Both authors listed relative quantity of lichen growth by tree species. Coleman et al. (1956) studied the growth of lichens and other epiphytes more intensively, ranking Olympic Peninsula tree species in terms of epiphyte receptivity. They found *Alnus rubra* to be the best epiphyte host, *Tsuga mertensiana* to be the worst host on the Olympic Peninsula of Washington. In Oregon, Pechanec and Franklin (1968) found *A. rubra* to be a better epiphyte host than either *Picea sitchensis* or *Pseudotsuga menziesii.*

FIRE RESISTANCE

Bark characteristics, foliage flammability, and epiphyte populations all contribute to the total flammability of northwestern tree species. This whole-tree flammability and relative species resistance to fire have been compared by several authors. In the interior, Tackle (1959) observed that *Pinus contorta* was more susceptible to fire than other *Pinus* species or *Pseudotsuga menziesii,* but was less susceptible than *Picea engelmannii* and *Abies lasiocarpa.* Kerr (1913) also found that *P. contorta* was more fire-susceptible than *P. ponderosa.* Flint (1925) compared the fire resistance of 11 northern Rocky Mountain conifers, finding *Larix occidentalis* to be most resistant and *Abies lasiocarpa* least resistant. He noted that intolerant trees of the northern Rocky Mountains tend to be highly fire-resistant, while tolerant ones tend to have low resistance.

Relative species fire resistance does not appear to be the same in coastal forests as it is farther inland. *Thuja plicata* is more severely damaged by fire than any of its associates along the coast, but is less susceptible than *Picea engelmannii, Tsuga heterophylla,* and *Abies lasiocarpa* in the Inland Empire (Boyd 1959). Therefore, the fire resistance ranking in table 18 was divided into coastal and interior portions. *Pseudotsuga menziesii* seems to be the most fire-resistant coastal species (Starker 1934). Starker listed *Picea sitchensis* as the least fire resistant of 13 Oregon and Washington trees. Farther south Stone and Vasey (1968) compared the

fire resistance of *Sequoia sempervirens* and its associates, noting that both *S. sempervirens* and *Lithocarpus densiflora* are more fire-resistant than *P. menziesii* and *Abies grandis*.

In the north, a survey of fire-killed timber on a burn in British Columbia showed that 50 percent of the *Thuja plicata*, but only 20 percent of the *Tsuga heterophylla* and only 1 percent of the *Pseudotsuga menziesii* trees were charred enough to degrade mill quality (Wallis, Godfrey, and Richmond 1974). When McNaughton (1944) studied charring and the ignition temperatures of wood, he found that speed of ignition was directly correlated with wood specific gravity. Species with low specific gravity (e.g., *Picea sitchensis*) ignited before species with high specific gravity (e.g., *Larix occidentalis*).

ROOTS

Root charring commonly occurs during severe forest fires, and species rooting characteristics probably are significant determinants of fire resistance. Young *Pinus ponderosa* roots grow deeper than *P. lambertiana* and *Libocedrus decurrens* roots, and the young *P. lambertiana* and *L. decurrens* roots tend to be deeper than *Abies grandis* or *Pseudotsuga menziesii* roots of the same age (Stein 1963). *Thuja plicata* roots are even shallower than those of *A. grandis* and *P. menziesii* (Ross 1932). *Tsuga heterophylla* seedling roots are shallower than the seedling roots of *Abies amabilis* (Scott et al. n.d.). Indeed, *Tsuga heterophylla* roots seem to be the shallowest of all (Haig 1936, Smith 1964). Although not compared directly with the above species, *Abies lasiocarpa* and *Picea glauca* apparently also have shallow roots--shallower than *Pinus contorta* (Eis 1970). *Pinus contorta* tends to be more shallow-rooted than *P. ponderosa* (Gail and Long 1935, Tarrant 1953).

Lateral extent, structure, and composition of species root systems vary even more than depth. *Populus tremuloides* probably has the greatest lateral root extent (Berndt and Gibbons 1958). *Picea glauca* roots spread laterally more than *Abies lasiocarpa* roots, and *A. lasiocarpa* root systems spread more than those of *Pinus contorta* when root spread was considered in relation to tree height (Eis 1970). When root spread was related to crown width in root spread/crown width ratios, species were ranked as follows (Smith 1964):

Pinus contorta (highest ratio)
Picea sitchensis
Pinus ponderosa
Pseudotsuga menziesii
Tsuga heterophylla
Thuja plicata
Alnus rubra (lowest ratio)

As crown widths of these species differ (table 18), absolute root spread may not always be greater in species with higher root spread/crown width ratios. For example, roots of the wide-crowned *Pinus ponderosa* actually spread more laterally than those of the narrow-crowned *P. contorta* (Tarrant 1953). Nevertheless, *Pseudotsuga menziesii* root spread is wider than that of either *Tsuga heterophylla* or *Thuja plicata* when considered on an absolute basis (Eis 1974). Absolute measurements of the total root masses of windthrown trees of four species (Steinbrenner and Gessel 1956) showed *Pseudotsuga menziesii* to have the most extensive root system, followed in descending order by *Abies procera, Tsuga heterophylla*, and *Thuja plicata*.

When *Pseudotsuga menziesii, Tsuga heterophylla*, and *Thuja plicata* root distribution and structure are considered further, other differences become evident. *T. plicata* roots are more numerous in the duff than in underlying soil where a heavy duff layer exists (Ross 1932). Ross found that *T. heterophylla* root tips were also present in this duff, but not to the same extent. He found very few *P. menziesii* feeding roots in the duff layer...they were deeper, in the underlying soil. Ross also observed that *T. heterophylla* roots were smaller than those of *P. menziesii*, tending to be more oval in cross section than the circular *Pseudotsuga* roots.

Eis (1974) observed larger root diameters in *Pseudotsuga menziesii* than in either *Tsuga heterophylla* or *Thuja plicata*. After hydraulic

excavation, he found that thin, rope-like roots were most dense on *T. plicata* trees, least dense on *P. menziesii*. In an earlier study Eis (1972) noted that root grafting occurred in all three species, but was most frequent in *T. plicata*, least frequent in *P. menziesii*. The grafts apparently were important aids to the survival of suppressed trees on Vancouver Island.

Farther inland, Eis (1970) studied root growth relationships of juvenile trees in interior British Columbia. For the same age, *Pinus contorta* root systems were denser than those of either *Picea glauca* or *Abies lasiocarpa*. Vertical "sinker" roots were more numerous in *P. contorta*. Its roots were more branched than those of *Picea glauca*. In western Montana, Wyoming, and Idaho, Gail and Long (1935) also studied the rooting relationships of *Pinus contorta* and its associates. They found that *P. contorta* lateral roots grew more horizontal and closer to the soil surface than those of *P. ponderosa*.

The root systems of *Pseudotsuga menziesii* var. *glauca*, *Abies grandis*, *Larix occidentalis*, *Pinus monticola*, and *Thuja plicata* grown in large containers were investigated by Leaphart and Wicker (1966). They found the best taproot development in *L. occidentalis*, followed by *P. menziesii* and *A. grandis*. Taproots in *T. plicata* and *P. monticola* were poorly defined. Fine roots apparently varied inversely with taproot development for *T. plicata* had the most profusely developed fine root system, and *L. occidentalis* had the least profuse system.

Root system strength is a crucial factor in maintaining the stability of steep forested slopes. Burroughs and Thomas (1977) compared the tensile strength of *Pseudotsuga menziesii* var. *menziesii* and *P. mensiesii* var. *glauca* roots, finding var. *menziesii* roots to be stronger when fresh. In similar studies, Ziemer and Swanston (1977) found live *Tsuga heterophylla* roots to be stronger than live *Picea sitchensis* roots. O'Laughlin (1973) found no significant difference in tensile strengths of *Pseudotsuga menziesii* and *Thuja plicata* roots.

WINDTHROW RESISTANCE

Root strength, depth, and structure affect the windthrow resistance of northwestern tree species--resistance that has been compared in several publications. The New Zealand Forest Service (1976) rated *Pseudotsuga menziesii* as more windfirm than most other conifers. Steinbrenner and Gessel (1956) also rated *P. menziesii* as most resistant, followed in order by *Abies procera*, *Tsuga heterophylla*, and *Thuja plicata*. Their *P. menziesii*-*T. heterophylla* comparison, based on large samples, is more reliable than their *A. procera* and *T. plicata* rankings, which were based on observations of only two and seven trees, respectively. When Gratkowski (1956) analyzed windthrow by comparing species composition of the stand with species composition of the windthrown trees, he found that short *Thuja plicata* trees growing on dry sites were most resistant, followed by *Pseudotsuga menziesii*, *Tsuga heterophylla*, and (least resistant) *Abies amabilis*. Boyd (1959) tentatively rated *Thuja plicata* fourth in Inland Empire windfirmness, exceeded by *Larix occidentalis*, *Pinus ponderosa*, and *Pseudotsuga menziesii*. Boyce (1929) found both *T. plicata* and *P. mensiesii* to be more resistant to windthrow than *Tsuga heterophylla*, *Abies amabilis*, or *Picea sitchensis* on the Olympic Peninsula. In the Oregon Coast Range, *P. sitchensis* is more windfirm than *T. heterophylla* (Ruth and Yoder 1953).

DENSE SOIL TOLERANCE

Soils interact with species characteristics in determining windthrow resistance, and even a windthrow-resistant species may fare poorly on shallow or dense soils tha[t] limit root penetration and growth. Northwestern tree species differ with respect to their growth in dense soils, however--some are able to tolerate rather high soil densiti[es] while others cannot.

On soils developed from Eocene t[o] Miocene volcanic rocks in the wester[n] Cascade Range, clay subsoils restric[t] *Pseudotsuga menziesii*, but not *Pinu[s]*

ponderosa or *P. lambertiana* roots (Stephens 1965). Cochran (1963) noted longer lateral roots and greater total root weights in *Pinus lambertiana* than in *P. ponderosa* during the initial stages of seedling development in high density soil. Soil density was one of the parameters utilized by Forristall and Gessel (1955) in comparing the growth of *Thuja plicata, Alnus rubra, Pseudotsuga menziesii,* and *Tsuga heterophylla* in Washington. Unfortunately, their soil density-growth comparisons probably were confounded by other factors, for the different species grew on plots with differing soil textures and moisture contents.

A uniform soil was artificially compacted to different bulk densities by Minore, Smith, and Woollard (1969) to compare the effects of high soil density on seedling root growth of seven northwestern species. In 2 years, the roots of *Pinus contorta, Pseudotsuga menziesii, Alnus rubra,* and *Abies amabilis* penetrated soil columns that the roots of *Picea sitchensis, Tsuga heterophylla,* and *Thuja plicata* did not. In another study, Leaphart (1958) found that *Larix occidentalis* and *Pinus monticola* roots penetrated hardpan layers more effectively than the roots of *Pseudotsuga menziesii, Pinus contorta, Abies grandis, Picea engelmannii, Thuja plicata,* or *Tsuga heterophylla.*

MECHANICAL DAMAGE RESISTANCE

Soil compaction probably is not very important when seedlings are buried by silt. Nevertheless, Hermann and Lavender (1967) observed less damage to *Pinus ponderosa* than to *Pseudotsuga menziesii* when dormant seedlings of both species were buried under silt for more than 8 weeks. Burial under litter that accumulates on top of the winter snow pack is resisted better by *Abies amabilis* than by *Tsuga heterophylla* seedlings (Thornburg 1969).

Damage caused by the snow pack itself varies greatly among species (table 18). *Tsuga heterophylla, T. mertensiana, Picea breweriana,* and *Abies magnifica* var. *shastensis* seem most resistant to snow damage. *Pinus monticola* and *Abies amabilis* are somewhat less resistant but able to tolerate snow weights better than *Abies concolor, A. procera,* or *Pinus jeffreyi* (Williams 1966, Waring et al. 1975). *Pseudotsuga menziesii, Pinus lambertiana,* and *P. ponderosa* seem to be most subject to snow damage of the species compared.

ANIMAL RELATIONSHIPS

Most animal damage in young stands seems to be caused by gophers, rabbits, or deer. No species comparisons are available for gopher damage, for available data indicate little or no species preference by these rodents. Differences in rabbit damage were noted by Worthington (1955), however, who found *Pseudotsuga menziesii* to be damaged more than *Thuja plicata* and *Tsuga heterophylla. Abies grandis* and *Picea sitchensis* were least damaged on Worthington's Olympic Peninsula sites. Staebler et al. (1954) also found *P. menziesii* to be more damaged by rabbits than *T. heterophylla.* The *Chamaecyparis lawsoniana* seedlings on their southwestern Washington plots were browsed by deer, but only after 3 years.

Schubert (1956) observed more deer browsing on *Abies concolor* than on *Pinus lambertiana,* and Stark (1965) found more browsing on *A. concolor* and *Libocedrus decurrens* than on *Pinus ponderosa* and *P. lambertiana. Abies magnifica* also seems to be less damaged by deer browsing than *A. concolor* (Gordon 1970). When both rabbit and deer damage are considered, comparative animal damage may be ranked by species groups:

Pinus ponderosa, P. lambertiana, Abies grandis, A. magnifica, and *Picea sitchensis* (least damaged)

Abies concolor, Libocedrus decurrens, and *Tsuga heterophylla*

Thuja plicata and *Chamaecyparis lawsoniana*

Pseudotsuga menziesii (most damaged)

Relative species palatability may influence relative species damage, but highly palatable species may not comprise the majority of an animal's diet. For example, *Thuja plicata* is a highly palatable, preferred deer food; but it occurred in only 20-30 percent of the deer stomachs sampled by Cowan (1945) on Vancouver Island, never amounting to more than 2 percent of the food volume. In contrast, *Pseudotsuga menziesii* occurred in 50-100 percent of Cowan's deer samples and accounted for 25-50 percent of their food volume.

Pseudotsuga menziesii seeds are eaten by rodents in preference to *Abies procera* seeds (Dick 1960). Small mammals and birds also seem to prefer *P. menziesii* seeds to the seeds of *Tsuga heterophylla* (Gashwiler 1970). They prefer *T. heterophylla* to *Thuja plicata* (Gashwiler 1967).

INSECT RESISTANCE

General insect resistance seems to be associated with species longevity. *Thuja plicata* is more insect-resistant than *Tsuga heterophylla* or *Abies amabilis* in coastal British Columbia (Schmidt 1955). It also is more resistant to insect attacks than most of its Inland Empire associates (Boyd 1959). *Thuja plicata* maintains this high insect-resistance rating when more limited insect categories are considered. It is attacked less by woodborers than *Pseudotsuga menziesii*, *Abies grandis*, or *Tsuga heterophylla* (Johnson 1958); and its extracts apparently induce more deaths in western tent caterpiller pupae than extracts of *P. menziesii* (Wellington 1969). *P. menziesii* is attacked by the silver-spotted tiger moth more often than *Thuja plicata*, *Tsuga heterophylla*, *Pinus contorta*, *Picea sitchensis*, *Abies amabilis*, and *A. grandis* in British Columbia (Sellars-St. Clare 1968). *Abies grandis* is damaged more than *P. menziesii* by western spruce budworm attacks, however, even when budworm egg numbers are similar in the upper crowns of these two species (Carolin and Coulter 1975).

The crowns of *Pinus lambertiana* and *P. monticola* seedlings were more seriously infested with woolly aphids than those of *P. albicaulis* when an accidental aphid infestation occurred during a lathhouse blister rust experiment (Hoff and McDonald 1977). Mitchell (1966), comparing *Abies* species in the field, observed that *A. concolor* and *A. procera* were most resistant to balsam woolly aphid. *Abies lasiocarpa* was least resistant (table 19).

Abies lasiocarpa also probably lacks resistance to termite attack, as do *Picea engelmannii*, *Tsuga heterophylla*, *Larix occidentalis*, and *Pseudotsuga menziesii*. Carter and Smythe (1974) found the woods of these species to be better termite food than the woods of *Thuja plicata*, *Sequoia sempervirens*, *Chamaecyparis lawsoniana*, and *Pinus ponderosa*. *Pinus ponderosa* apparently is cutworm resistant as well. When Fowells (1940) and Fowells and Stark (1965) tallied cutworm damage to seedlings in California, they found *Pinus lambertiana* to be least damaged, followed by *P. ponderosa* and *P. jeffreyi* (table 19). The cutworms showed a preference for *Libocedrus decurrens* over *Abies concolor* and the *Pinus* species.

Further comparisons of insect resistance among northwestern species are complicated by host specificity problems. Many serious insect pests attack only one or two tree species, and literature references to comparative species resistances are unavailable for them.

Table 19--Comparative insect resistance of northwestern tree species[1]

Cutworms[2]	Wood borers[3]	Termites[4]	Balsam woolly aphid[5]	Woolly aphid[6]
Pinus lambertiana	*Thuja plicata*	*Thuja plicata, Chamaecyparis lawsoniana, Sequoia sempervirens, Pinus ponderosa*	*Abies procera, A. concolor*	*Pinus albicaulis*
Pinus ponderosa, P. jeffreyi	*Pseudotsuga menziesii, Tsuga heterophylla, Abies grandis*	*Picea engelmanni, Tsuga heterophylla, Larix occidentalis*	*Abies magnifica* var. *shastensis*	*Pinus monticola*
Abies concolor		*Abies lasiocarpa, Pseudotsuga menziesii*	*Abies grandis*	*Pinus lambertiana*
Libocedrus decurrens			*Abies amabilis*	
			Abies lasiocarpa	

1/ Resistant species are listed above susceptible ones. Species in the same group are not necessarily equal, but data are insufficient for species comparisons within groups.

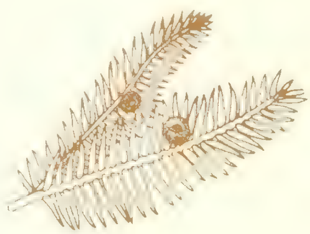
2/ From Fowells (1940) and Fowells and Stark (1965).

3/ From Johnson (1958).

4/ From Carter and Smythe (1974).

5/ From Mitchell (1966).

6/ From Hoff and McDonald (1977).



DISEASE RESISTANCE

Comparing disease resistance of northwestern tree species also is complicated by host specificity. Many pathogens, though widespread, are limited to a small number of host species. Other diseases consist of many pathogens attacking many trees, with each pathogenic species preferring a single tree species. The dwarf mistletoes are an example. Smith (1974) inoculated several tree species with several dwarf mistletoe species. He observed that each had a principal host on which it was particularly infectious, but they were not strictly host-specific. The greatest mistletoe seed retention occurred on the branches of *Picea engelmannii*, *P. sitchensis*, and *P. glauca*. The poorest occurred on *Pinus ponderosa* and *Larix occidentalis*. In contrast, the best mistletoe seed germination was on *Tsuga heterophylla*, *Pseudotsuga menziesii*, *Pinus ponderosa*, and *Abies grandis*; the poorest was on the *Picea* species.

Host specificity sometimes is evident within a single genus. For example, northwestern *Pinus* species exhibit some differential resistance to attack by rust fungi. *Pinus contorta* is more resistant to comandra rust than *P. ponderosa* (Bergdahl and French 1976). *P. monticola*, though susceptible, is less susceptible to white pine blister rust than other northwestern five-needled *Pinus* species. *Pinus albicaulis* is most susceptible and *P. lambertiana* is intermediate (Childs and Bedwell 1948).

Unfortunately, all northwestern *Pinus* species seem to be equally susceptible to annosus root rot (Bega 1962). In California they die soon after *Fomes annosus* invades and rapidly kills the cambium.

This does not happen in other California conifers. Instead, the fungus causes a chronic decay condition which the *Abies* species and other non-*Pinus* conifers appear to tolerate for several years (Bega and Smith 1966). *Pinus* species may be more tolerant in Britian than they are in California, for Aldhous and Low (1974) subjectively rated the pines as being more resistant than other conifers to *Fomes* butt rot. These other conifers do possess varying degrees of susceptibility to annosus root and butt rot, however, wherever they are grown (table 20). *Tsuga heterophylla* and *Picea sitchensis* are less resistant than *Abies grandis*, *A. procera*, and *Pseudotsuga menziesii* in Britian, where *Thuja plicata* is relatively susceptible (Aldhous and Low 1974). In British Columbia *Pseudotsuga menziesii* roots are more resistant than *Tsuga heterophylla* roots, and *Thuja plicata* stumps are more resistant to *Fomes* spore infection than the stumps of other conifer species (Wallis and Ginns 1968).

Tsuga heterophylla seedlings are more susceptible than *Pseudotsuga menziesii* seedlings to *Rhizina undulata*, a root pathogen that can be serious where slash has been burned (Morgan 1973).

Table 20--Comparative decay resistance of northwestern tree species[1/]

Annosus root and butt rot[2/]	Laminated root rot[3/]	Decay in living trees[4/]	Decay in dead wood[5/]
Pseudotsuga menziesii, Abies procera, A. grandis	*Acer macrophyllum, Alnus rubra, Arbutus menziesii, Lithocarpus densiflora, Populus trichocarpa, P. tremuloides*	*Pinus ponderosa*	*Thuja plicata, Sequoia sempervirens, Taxus brevifolia*
Tsuga heterophylla, Picea sitchensis	*Libocedrus decurrens, Pinus ponderosa, Thuja plicata*	*Pinus monticola, P. lambertiana*	*Larix occidentalis*
	Pinus contorta, P. monticola	*Pinus contorta*	*Pseudotsuga menziesii*
	Abies lasiocarpa, Larix occidentalis, Picea engelmannii, P. sitchensis, Tsuga heterophylla	*Sequoia sempervirens*	*Pinus ponderosa, P. lambertiana, Picea sitchensis*
	Abies amabilis, A. grandis, Pseudotsuga menziesii, Tsuga mertensiana	*Picea sitchensis*	*Pinus monticola, P. contorta, Abies procera, A. concolor, A. amabilis, Tsuga heterophylla, Picea engelmannii*
		Pseudotsuga menziesii	
		Abies species	
		Tsuga heterophylla	

[1/]Resistant species are listed above susceptible ones. Species in the same group are not necessarily equal, but data are insufficient for species comparisons within groups.

[2/]From Aldhous and Low (1974) and Wallis and Ginns (1968).

[3/]From Hadfield and Johnson (undated).

[4/]From Buckland et al. (1949), Wagener and Davidson (1954), and Farr et al. (1976).

[5/]From Boyce (1929), Englerth and Scheffer (1954), USDA Forest Products Laboratory (1955), and Clark (1957).

When Vaartaja (1957) germinated seven northwestern tree species on agar cultures of a damping-off fungus (*Phytophthora cactorum*), he found *Thuja plicata* to be much more resistant than *Larix laricina*, and *L. laricina* was more resistant than *Picea glauca*, *P. mariana*, *P. sitchensis*, *Pinus contorta*, or *P. ponderosa*.

Another fungus, the laminated root rot caused by *Phellinus (Poria) weirii*, has been studied extensively. It occurs on many northwestern species. *Thuja plicata*, *Alnus rubra*, and *Acer macrophyllum* have more resistance to this fungus than *Pseudotsuga menziesii* (Wallis and Reynolds 1967). *Phellinus* infected roots have profuse ectotrophic mycelium in *Pseudotsuga menziesii* and *Tsuga heterophylla*; limited mycelium in *Pinus monticola*, *P. contorta*, and *P. ponderosa*; and almost no mycelium in *Thuja plicata* (Wallis 1976). Hadfield and Johnson (undated) compared host susceptibility in the summary publication used as a source for the species comparisons listed in table 20.

Table 20 summarizes the general decay information available in several literature sources. Living *Picea sitchensis* trees less than 400 years old are relatively free of rot in southeastern Alaska; *Tsuga heterophylla* trees are not (Farr et al. 1976). *Abies amabilis* less than 350 years old on Vancouver Island also is more resistant to infection by wood-rotting fungi than *Tsuga heterophylla* (Buckland et al. 1949). When heart rot in *Abies* species is compared with rot in other genera, it is less prevalent than in *Tsuga*, but more prevalent than in *Pseudotsuga* or *Picea* (Wagener and Davidson 1954). Within genera, Wagener and Davidson's data indicate that living *Pinus ponderosa* has less heart rot than *P. monticola* and *P. lambertiana*.

Pinus ponderosa and *P. lambertiana* were more decay-resistant than *P. monticola*, *P. contorta*, *Abies procera*, *A. concolor*, *Tsuga heterophylla*, and *Picea engelmannii* when Clark (1957) exposed heartwood samples to wood-rotting fungi in the laboratory. Clark found *Pseudotsuga menziesii* heartwood to be even more resistant than the *Pinus* species. In similar laboratory tests, Englerth and Scheffer (1954) found *Larix occidentalis* to be more decay-resistant than *Pseudotsuga menziesii* but less resistant than *Thuja plicata*. *Thuja plicata* was also found to be more decay-resistant than the wood of other species by Boyce (1929) and Wallis et al. (1974). Boyce, studying the deterioration of windthrown timber on the Olympic Peninsula, recorded more decay in *Abies amabilis* and *Tsuga heterophylla* than in *Picea sitchensis*, more in *P. sitchensis* than in *Pseudotsuga menziesii*.

When Childs (1939) studied the deterioration of slash on clearcut areas in the Douglas-fir region, he found the rate of sapwood decay to be about the same in *Pseudotsuga menziesii*, *Picea sitchensis*, and *Tsuga heterophylla* slash. *P. menziesii* heartwood decayed more slowly than the other two species, however, and heartwood decay in *Picea sitchensis* was slower than in *Tsuga heterophylla*. Similar reports were reported by Roff and Eades (1959) and by Ruth and Harris (1975). *Tsuga heterophylla* and *Abies amabilis* heartwood decay faster than the heartwoods of *Picea sitchensis* and *Pseudotsuga menziesii*. *Thuja plicata* is slowest to decay.

When root decay rates are compared, species ranking changes slightly. As one would expect, *Thuja plicata* roots lose their tensile strength more slowly than *Pseudotsuga menziesii* roots (O'Laughlin 1973). *Picea sitchensis* roots decay faster than *Tsuga heterophylla* roots in southeastern Alaska, however (Ziemer and Swanston 1977), reversing the relative heartwood decay rates of these two species.

CHEMICALS

Most chemically oriented species comparisons in the literature refer to chemical damage, not benefits. For example, smoke from slash burning apparently damages *Pseudotsuga menziesii* more than *Pinus lambertiana* or *P. ponderosa*, which are damaged more than *Libocedrus decurrens* or *Abies grandis* (Stein 1963). Nevertheless, some chemical effects are beneficial. Germination rates may be accelerated by applying hydrogen

Figure 1--A summary of autecological comparisons for the major northwestern tree species, with page numbers to indicate where the comparisons are found.

[illegible]	[illegible]																					
[illegible]	[illegible]	50,51	[illegible]	[illegible]		[illegible]				0,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]					[illegible]			[illegible]		[illegible]			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	25,[illegible]		[illegible]	[illegible],6		[illegible]			[illegible]					[illegible]			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]		[illegible],31			[illegible]	38		[illegible]	3[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible],11	[illegible],51	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	3[illegible]	[illegible]	3[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]6	[illegible]	[illegible]	[illegible]	3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3[illegible]	[illegible]
Crown density	[illegible]		[illegible]	37						[illegible]		37		[illegible]			37	[illegible]	[illegible]	[illegible]	[illegible]	
Crown [illegible]		[illegible]	[illegible]	[illegible]		37				[illegible],37		[illegible]	[illegible]	37			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Crown [illegible]		[illegible]	[illegible]	[illegible]						[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Crown [illegible]			37							37,[illegible]		3[illegible]		[illegible]			37,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
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[illegible]	3[illegible],[illegible]		[illegible]				45			[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Drought tolerance	11,1[illegible]	[illegible]	[illegible]	11,[illegible]	11,1[illegible]	14		11,1[illegible]		11,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11,[illegible]
[illegible]		18	18	[illegible]		[illegible]	[illegible]		[illegible]	3[illegible]		3[illegible]	[illegible]	[illegible]			[illegible]		[illegible]	[illegible]	3[illegible],13	[illegible]
Fire [illegible]		[illegible]	3[illegible],33	[illegible]		[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	39,4[illegible]	[illegible]	[illegible]	[illegible]
Foliage flammability		[illegible]	[illegible]	38		38				3[illegible]		[illegible]	[illegible]	[illegible]			3[illegible]	[illegible]	[illegible]	3[illegible]	3[illegible]	38
Frost tolerance	6,7	6,7	[illegible]	[illegible]	7		6,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6,7, 8	[illegible]	[illegible]
Germination rate	3[illegible]	[illegible]	[illegible]		[illegible]	[illegible],31					3[illegible],31	[illegible]			[illegible]	3[illegible]	[illegible]	[illegible]	3[illegible],31, 3[illegible]		31	
Heat tolerance			[illegible]	[illegible]						[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
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Insect resistance	46,47	46,47	46,47	46,47	47	46,47		46,47		46,47	46,47	46,47	[illegible]	[illegible]	46,47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]		[illegible]		6					[illegible]	[illegible]						[illegible]		[illegible]	
Litter fall	[illegible]						[illegible]						[illegible]	37,38			[illegible]	[illegible]	[illegible]	37,[illegible]	37	
Longevity	[illegible]	[illegible]	[illegible]	[illegible]		13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	13	[illegible]	[illegible]	[illegible]	[illegible]
Moisture [illegible]			12,13	12,13			12,13		13			1[illegible]	1[illegible],13	1[illegible],13	13	1[illegible]		12,13	[illegible]	[illegible]	[illegible]	[illegible]
Moisture (optimum)	14	14	14	1[illegible]	14	14	1[illegible]	1[illegible]			1[illegible],14	14	13	1[illegible]		14		1[illegible],14	1[illegible],14	14	14	14

attributes	AbAm	AbCo	AbGr	AbLa	AbMa-sh	AbPr	AlRu	ChLa	ChNo	LaOc	LiDe	PiEn	PiSi	PiCo	PiJe	PiLa	PiMo	PiPo	PsMe	ThPl	TsHe	TsMe
Needle density							35						35	35			35		35		35	
Needle longevity	36		36										36	36			36	36	36		[illegible]	
Needle volume			36										36	36			36		36		36	
Needle weight	36		36										36	36			36		36		36	
Nutrient concentrations	15,16,17		15,16	15,16,17	16		16,17	15,17		16,17		15,16,17	15,16,17	16,17			16	16,17	15,16,17	15,16,17	15,16,17	
Nutrient deficiencies	19	19	19	19	19				19		19	18,19	17,18,19	[illegible]	19	19	17,18,19	17,18,19	17,18,19	17,18,19	[illegible]	19
Nutrient [illegible]													19	19					19	19	19	
Root growth rate			[illegible]	[illegible]						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Rooting depth	43		39,43	43						39	39,43			43		39,43	39	39,43	39,43	39,43	39,43	
Sapwood thickness						40				38		38		38				38,40	38,40	38		
Seed bearing age	26	26		25	26	[illegible]	26	26		26		25	26	26	26	26	26	26	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]			[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
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Figure 1--A summary of autecological comparisons for the major northwestern tree species, with page numbers to indicate where the comparisons are found.

attributes	AbAm	AbCo	AbGr	AbLa	AbMa-sh	AbPr	AlRu	ChLa	ChNo	LaOc	LiDe	PiEn	PiSi	PiCo	PiJe	PiLa	PiMo	PiPo	PsMe	ThPl	TsHe	TsMe
Needle density							35						35	35			35		35		35	
Needle longevity	36		36										36	36			36	36	36		[illegible]	
Needle volume			36										36	36			36		36		36	
Needle weight	36		36										36	36			36		36		36	
Nutrient concentration	15,16,17		15,16	15,16,17	16		16,17	15,17		16,17		15,16,17	15,16,17	16,17			16	16,17	15,16,17	15,16,17	15,16,17	
Nutrient deficiencies	19	19	19	19	19				19		19	17,19	17,18,19	19	19	19	17,18,19	17,18,19	17,18,19	17,18,19	18,19	19
Nutrient excesses													19	19					19	19	19	
Root growth rate			[illegible]	21						[illegible]	[illegible],22	[illegible]	[illegible]	[illegible]		[illegible]	22,[illegible]	[illegible]	[illegible],33	[illegible]	[illegible]	
Rooting depth	43		39,43	43						39	39,43			43		39,43	39	39,43	39,43	[illegible],43	[illegible],43	
Sapwood thickness						[illegible]				[illegible]		[illegible]		[illegible]				[illegible],40	[illegible],40	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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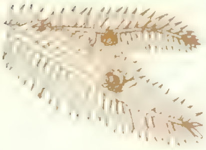
[illegible]

As one would expect, widespread species have been compared more than those with limited ranges. *Chamaecyparis lawsoniana* comparisons are particularly scarce. As. *C. lawsoniana* is a valuable species seriously threatened by disease, its autecological attributes probably should be related to those of other species. Such autecological comparisons might help pathology researchers and provide information about suitable substitutes if *C. lawsoniana*'s ecological niche must be occupied by other species.

Pinus jeffreyi appears to be another species that seldom has been compared because of its limited range. It may resemble *P. ponderosa* in some cases where blanks appear in figure 1, but probably has several unique attributes that are not matched in other species. Nutrient concentrations and mean temperature comparisons seem particularly worthy of investigation in *P. jeffreyi*.

Limited range probably does not account for the surprising lack of *Alnus rubra* comparisons. Its low commercial value may be responsible. Whatever the reason, *A. rubra* comparisons should be neglected no longer. Root growth rate and rooting depth relationships seem particularly pertinent in light of *A. rubra*'s nitrogen fixing characteristics (Tarrant and Miller 1963, Bollen et al. 1967, Franklin et al. 1968, and Tarrant et al. 1969). Its tolerance of nutrient deficiencies also should be compared with associated species.

Associated species probably should be compared in as many ways as possible, wherever they grow. Considerable amounts of work remain to be done if this is to be accomplished for the autecological attributes listed here. Comparative crown, needle, and root characteristics, litter fall, slash flammability, and windthrow resistance are all sparsely represented in figure 1.



UNKNOWN ATTRIBUTES

The autecological attributes compared in this report are somewhat subjective. They represent attempts to delineate and define discrete variables in the non-discrete continuum of interacting characteristics that define the nature and properties of northwestern tree species as we know them. Others might use somewhat different categories or discuss these attributes under different headings. Nevertheless, the attributes do exist as such, and most have been compared in this report--however one wishes to categorize and name them.

Some attributes have not been compared, however, for they seem to be absent from the literature. As comparable information is lacking, these attributes constitute unknowns...not just for one or two but for most northwestern tree species.

Most northwestern tree species grow in mixed stands, where they compete with other species. Relative ability to compete constitutes an autecological unknown. Unfortunately, it is an unknown that must be qualified by knowing where the competition will occur and in what environment. Comparative competitive abilities probably will remain unknown until they are determined in various environments throughout the natural ranges of the species involved.

Potential species ranges constitute another unknown autecological attribute. Where would each species occur if it possessed a capacity for worldwide distribution and was not limited by competition with other species? A complete knowledge of all other attributes, for all species, may be a prerequisite to answering this question. It probably will remain unanswered for the forseeable future.

Fortunately, several other attributes are less likely to remain unknown. Study of mycorrhizal relationships is now being accelerated, and detailed comparisons among northwestern species should be available in a few more years. Although the fungus-host relationships may be rather specific, it should soon be possible to rate

northwestern tree species in terms of mycorrhizae dependence and numbers of fungi involved.

Genetic variability and gene-pool characteristics also are being studied for several northwestern tree species. Genetic plasticity may vary greatly among species, and some gene pools probably are larger and more complex than others. Better understanding of these presently unknown genetic attributes may permit species comparisons that are impossible today. It also should improve all present species ratings by facilitating evaluation of within-and-among species variations.

Although coniferous forests selectively filter light (Atzet and Waring 1970), among-species comparisons of light filtering properties and foliage albedo were not found in the literature--apparently because they are little known for northwestern tree species. Like many of the comparisons missing for individual species, these attributes probably will be recorded and compared as the needed research is accomplished.

RESEARCH NEEDS

Additional research is needed to supply the missing information indicated by blank spaces in figure 1 and to describe the unknown attributes discussed above. More than this is needed, however, even for the filled spaces in figure 1 and for well-known autecological attributes. Many of the comparisons cited here were based upon observations rather than measurements, and most occurred under conditions that could have influenced the results by introducing imperceptible extraneous influences. Quantification and refinement of these comparisons through rigorous experimental procedures carried out under controlled conditions should result in more consistent, reliable conclusions.

Quantitative comparison of photosynthetic activity under various light conditions has been accomplished for few species. It should be done for all, at several ambient temperatures. Photoperiodic responses also should be compared to determine relative light requirements for strobilus formation, anthesis, and dormancy. Again, several ambient temperatures should be used to investigate the light, temperature, and species interactions.

Species-environment interactions probably are as important as species attributes themselves when growth is being compared in the field. These interactions should be studied carefully by establishing replicated species trials in many different field environments. Wherever possible, these field environments should be categorized by quantitative measurements. They should always be classified or described in ways that allow comparison and contrast with other environments.

Growth comparisons in the field often require long-term experiments that may exceed the professional life span of any single researcher. Comparisons of germination rates, stratification requirements, and optimal germination temperatures do not have this inherent disadvantage. Environmental interactions are also important in these short-term comparisons, however, and they should be accomplished in carefully designed experiments that will result in usable interaction data.

Finally, it should be emphasized that two or more species should be tested together and compared whenever possible in autecological experimentation. Even the most well-designed experiment, carried out under highly controlled conditions, is somewhat unique. Exactly identical conditions are impossible to attain again, regardless of the precautions taken. Comparative data involving more than one species may allow further extrapolation of experimental results than that which is possible with a single species, and wider inferences often may be made. Relative comparisons tend to be more widely applicable than absolute, isolated results.

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GENERAL TECHNICAL REPORT PNW-88
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ANAGEMENT OF ESTERN HEMLOCK-KA SPRUCE ORESTS R TIMBER RODUCTION

ERT H. RUTH and A. S. HARRIS

ABSTRACT

Ecological and management information for the coastal western hemlock-Sitka spruce forests is summarized in this report. Areas of emphasis include logging methods, silvicultural systems, natural and artificial regeneration, residue disposal, weed control, thinning, growth and yield, and forest protection. Consideration is given site protection and nontimber values as well as timber management.

KEYWORDS: Western hemlock, *Tsuga heterophylla*, Sitka spruce, *Picea sitchensis*, timber management, management (forest), regeneration (stand), site preparation, silviculture.

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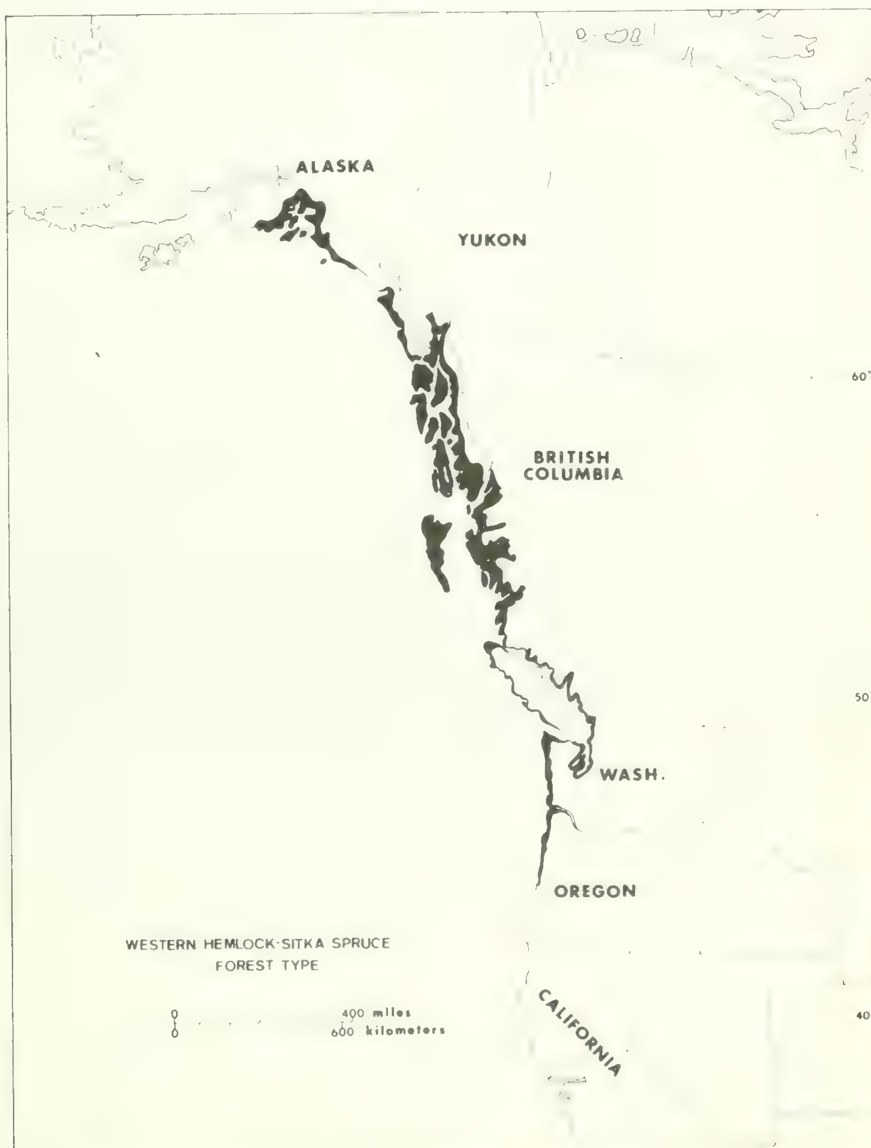
INTRODUCTION

This report summarizes current knowledge on silviculture of estern hemlock-Sitka spruce forests.[1] The intent is to provide ractical information for managing these forests for timber production. nphasis is on Oregon, Washington, and Alaska more than on British olumbia, although ecologically the type is a continuum; environmental onditions and forest stands gradually vary with latitude. In general, nformation and silvicultural recommendations for Oregon, Washington, nd Alaska apply in British Columbia as well.

THE HEMLOCK-SPRUCE TYPE

The hemlock-spruce type as defined here occupies a narrow 2,000-mi- (3 200-km-) long band along the Pacific coast from near Coos Bay, regon, to Prince William Sound, Alaska (fig. 1). Through most of this



gure 1.--Approximate range of the western hemlock-Sitka spruce forest type where mixtures of western hemlock and Sitka spruce occur in commercial forest stands.

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[1] Common and scientific names of plants are listed in the appendix.

distance, the type is roughly defined by the commercial range of Sitka spruce. Toward the south, hemlock extends farther inland and merges with Douglas-fir. At the northwestern extreme, the hemlock-spruce type is defined roughly by the range of western hemlock. Pure stands of Sitka spruce extend farther west to Afognak and Kodiak Islands. Spruce prefers a cool, moist, maritime climate without pronounced summer drought. These conditions are characteristic of the coastal fog belt and identify the forest environment under consideration here. Transitions from hemlock-spruce to pure hemlock in Oregon and Washington and to pure spruce in Alaska often are gradual, and much of the information presented here is applicable in these areas.

In Alaska the hemlock-spruce type is well defined. A series of icefields and high mountain passes above timberline form a distinct separation between the moist coastal forests and the dry white spruce-hardwood forests of interior Alaska and the white spruce-fir-hemlock forests of interior British Columbia. The type reaches its greatest extent in southeast Alaska. Here it extends from sea level to timberline on the offshore islands and on the mainland, covering a width of some 130 mi (210 km). Timberline may extend to 3,500 ft (1 000 m); occasional trees are found to 3,900 ft (1 200 m). Timberline is influenced locally by wind, aspect, snow accumulation, and avalanching. On the mainland the type extends inland several miles along fjords and inlets. Inland penetration is restricted to a few locations along the major rivers such as the Stikine and Taku, and at the head of Lynn Canal.

Farther northwestward along the Gulf of Alaska, the hemlock-spruce type narrows greatly, limited by steep mountains and piedmont glaciers edging the sea. Within Prince William Sound, the type again widens to some 60 mi (90 km), including the islands and a narrow mainland strip. Timberline lowers toward the northwest, occurring at 1,000 to 1,500 ft (300 to 450 m) on the Kenai Peninsula.

West of Prince William Sound, western hemlock is replaced by mountain hemlock along the southern tip of the Kenai Peninsula, and Sitka spruce becomes the predominant species. On the Kodiak-Afognak archipelago Sitka spruce is the only conifer present. Here it is expanding its range into a tundra-grassland complex at the rate of about 1 mi (1.6 km) per century (Griggs 1934, 1937). For management purposes then, the northwestern limit of the western hemlock-Sitka spruce type lies within Prince William Sound.

South of Alaska the hemlock-spruce type is less well defined. Within British Columbia, the Queen Charlotte Islands lie entirely within the type; along the northern mainland from Portland Canal south to Vancouver Island the type extends inland several miles along fjords and channels. Farthest inland penetration is along the Skeena River Valley where coastal hemlock-spruce first merges with western hemlock which grades into interior forest types.

On Vancouver Island the hemlock-spruce type is prominent on the low-lying northern tip north and west of Holberg. Farther south, it is restricted to a narrow strip along the west coast with stringers extending inland along major streams (Packee 1974a, 1974b). Eastward on Vancouver Island and along the adjacent mainland, the type grades

ito hemlock or hemlock-fir in response to drier climatic conditions. Hre Sitka spruce is relegated to river bottoms and moist upland sites nar tidewater.

In Washington, the most extensive area of the hemlock-spruce type i on the lower elevations of the Olympic Peninsula with stringers etending inland along major streams. Occasionally it reaches 3,000 ft (00 m) in elevation in especially moist situations in the Olympic Muntains. Farther south, the type narrows, occupying the coastal srip and lower elevations, grading into the hemlock type as drier cnditions prevail (Juday 1976). Midway along the Oregon coast, the tpe may reach elevations of 1,500 to 1,800 ft (450 to 550 m) within 6 mi (10 km) of tidewater and would undoubtedly reach higher if tpography permitted (fig. 2). However, higher elevations for the mst part lie too far inland, where dry summer conditions are unmodifed by frequent summer fog. In many areas the type may extend inland fr 6 mi (10 km) or more, and along streams or rivers it may extend iland for 20 mi (30 km). From the standpoint of management, the type bcomes insignificant south of Coos County, Oregon; although in southern Oegon and northern California, it is found intermittently, confined t seaward slopes and certain north-facing slopes and valley bottoms.

Figure 2.--Along the Oregon coast the hemlock-spruce type occurs at low elevations near the sea. The stand in foreground originated after a fire and includes a high percentage of red alder. Salmon River estuary, Cascade Head Scenic-Research Area, Oregon.

CIMATE

The hemlock-spruce type is confined to an area of maritime climate wth abundant moisture throughout the year, relatively mild winter

temperatures, and cool summers. Lack of a pronounced summer drought is perhaps the most important factor affecting vegetation. The combination of warm water from the Japan Current offshore and prevailing westerly onshore winds result in cool, humid conditions throughout the type.

Precipitation accompanies cyclonic, low pressure systems that approach from the sea, carried by the prevailing westerlies. From about mid-May to mid-September an extensive high pressure area dominates the weather along the Pacific coast off Oregon, Washington, and southern British Columbia, diverting storm tracks northward toward the Gulf of Alaska, where the low pressure systems become semipermanent. As a result, summer precipitation tends to be greater toward the north. Along the southern Alaska coast frequent light summer drizzle is the rule, with occasional fog along the outer coast. At Cordova, Alaska, on the average during June to September, a trace or more of precipitation occurs during 22 to 24 days of each month (table 1).

Table 1--Mean annual and selected monthly data for representative stations within the hemlock-spruce type, 1950-74

Station	Latitude, N.	Longitude, W.	Degree-days[1]	Precipitation	July precipitation	Days per month with trace or more of precipitation				Snowfall	Frostfree days
						June	July	August	September		
				cm	cm					cm	
Brookings, Oregon	42°03'	124°17'	2 511	204.9	0.4	9	6	7	8	1	294
Otis, Oregon	45°02'	123°56'	2 131	250.2	2.8	15	8	9	12	13	192
Forks, Washington	47°57'	124°22'	1 942	297.8	5.4	14	9	12	12	43	190
Quatsino, B.C.	50°32'	127°37	1 697	235.2	4.4	10	10	13	15	58	200
Langara, B.C.	54°15'	133°03'	1 204	165.5	7.4	19	20	20	22	71	241
Annette, Alaska	55°02'	131°34'	1 408	298.0	13.1	20	19	20	21	142	210
Sitka, Alaska	57°04'	135°21'	1 221	214.4	11.7	20	19	21	24	114	196
Juneau, Alaska	58°22'	134°35'	1 014	134.5	10.7	21	21	22	23	279	129
Cordova, Alaska	60°30'	145°30'	851	226.6	17.5	22	24	23	22	340	111
Seward, Alaska	60°07'	149°27'	989	151.4	7.2	16	16	19	20	221	153

[1] Base: 5°C.

Toward the southern part of the hemlock-spruce type, precipitation is less frequent during the summer. For example, at Otis, Oregon, a trace or more of precipitation occurs from 8 to 15 days per month during July to September. During these months fog and moist maritime air apparently play a particularly important role in maintaining moist conditions necessary for the hemlock-spruce type. During the summer fog commonly forms, covering coastal lowlands and following river drainages. The extent of fog penetration depends on heat loss to the atmosphere at night. During cloudy weather, air temperatures over land and sea are relatively equal. During clear weather, however, heat loss from the land is greater and with offshore wind fog may penetrate for 20 mi (30 km) up the longer drainages. As daytime temperatures rise fog is dissipated, often by midmorning in interior areas. It may remain

throughout the day along the coast. Fog collects on tree crowns and drips to the ground, adding as much as 25 percent to the total precipitation reaching the ground (Isaac 1946). This "fog drip" is an important factor in reducing fire danger and providing soil moisture during the growing season. In addition, moisture-laden air results in reduced transpiration, which helps trees to conserve moisture.

Total annual precipitation tends to be high throughout the type, apparently little influenced by latitude (table 1). The high mountains bordering the sea, narrow fjords leading inland, and other local topography greatly influence total precipitation. For example, the Juneau Airport, situated on a glacial flat in the lee of 3,000-ft (900-m) mountains, receives 53 in (135 cm) of precipitation annually; 9 miles (15 km) away the city of Juneau, located on the windward slope of a narrow fjordlike channel, receives 92 in (234 cm).

Depth of snowfall during the winter decreases southward. Based on snowfall records over a 25-year period, average depth of annual snowfall is 134 in (340 cm) at Cordova, Alaska, compared with 23 in (58 cm) at Quatsino, British Columbia; 5 in (13 cm) at Otis, Oregon; and 0.5 in (1 cm) at Brookings, Oregon (table 1).

Summer temperatures within the hemlock-spruce type tend to be cool and equable, lacking the extremes found within many other forest types. Length of growing season and total solar energy received during the growing season vary considerably over the 19° of latitude spanned by the type. Cumulative growing degree-days[2/] during the growing season range from 4 520°F-days (2 511°C-days) at Brookings, Oregon, to 1 532°F-days (851°C-days) at Cordova, Alaska (table 1 and unpublished data on file at Forestry Sciences Laboratory, Juneau, Alaska). This wide range of temperatures during the growing season accounts for much of the variation in productivity, soil development, and species composition within the type.

GEOLOGY AND SOILS

The physiography, geomorphology, and major geological features for various portions of the hemlock-spruce type have been described for Oregon (Baldwin 1964); Washington (Campbell 1962); British Columbia (Holland 1964); and Alaska (Reed 1958, Miller 1958). In addition, the major physiographic events of the late pleistocene have been summarized by Heusser (1960).

On the Olympic peninsula in Washington and southward into Oregon, soils have developed from basalts, sandstone, tuffs, and breccias. Unconsolidated deposits of sand, silt, and gravel occur along most streams. Glacial till or outwash is locally evident on the Olympic Peninsula; the southern extent of pleistocene glaciation is located about 6 mi (10 m) south of the Ozette River (Arnold 1906).

Northward in British Columbia and Alaska, glaciation has been an important factor in shaping the landscape and in the distribution of soil parent material. Most valleys tend to be U-shaped as a result of glaciation. Glacial till of varying thickness covers much of the valley bottoms and extends far up the sideslopes.

2/ Growing degree-days are based on average daily temperature above a threshold temperature of 41°F (5°C).

In southeast Alaska, most exposed rock is of paleozoic age, with large areas of granitic, metamorphic, and volcanic rock. Metamorphic rocks are intruded with dikes, sills, stocks, and small batholithic masses. Granitic rocks (mostly granodiorite) form the bulk of the larger mountain systems. Extensive areas of limestone occur in some areas (Buddington and Chapin 1929).

Soils vary by latitude within the hemlock-spruce type. In the Coast Ranges of Oregon and Washington, inceptisols and ultisols are the most widespread soils; on the Olympic Peninsula, inceptisols are the most common. Spodosols are less abundant (Franklin and Dyrness 1973, Heilman 1976). On Vancouver Island, British Columbia, spodosols and inceptisols are common over most of the island. Toward the northern portion of the island on the western coastal plains, histosols are common (Keser and St. Pierre 1973). In Alaska, spodosols and histosols are the most common soils (Sheehy 1975, Gass et al. 1967). Throughout the type, entisols are found along streams. In southeast Alaska, all mature soils under timber have strongly developed spodic horizons (Stephens 1969a).

In general, soils tend to be less well developed northward. In Alaska very immature soils are found in locations that have undergone recent glacial recession (Chandler 1942, Crocker and Dickson 1957, Ugolini 1966).

Research on forest soils has been carried on for many years in the Pacific Northwest, although most has been done outside the hemlock-spruce type (Tarrant 1964b, Klock 1969). Detailed comparison of soil characteristics within the hemlock-spruce type has not been made, although such a comparison would certainly be of value to the land manager in determining the applicability of published research results throughout the type. Existing information suggests that differences in soil properties at widely divergent points are great. For example, in comparing soils on the Alsea drainage in Oregon with soils in southeast Alaska, Stephens (1966) found the average depth of surface organic matter to be five times greater in Alaska; clay content three times lower.

In Alaska most spodosols have low clay content. Collodial organic and iron compounds are the main source of cation exchange capacity and water retention in these soils (Stephens 1969, Holty and Heilman 1971). They have relatively high moisture retention ability and relatively high rates of water transmission (Patric and Swanston 1968). Thixotropic properties of some horizons make these soils unstable and unsuitable for many engineering purposes (Bishop and Stevens 1964, Stephens 1966).

Despite their diverse parent material, spodosols in Alaska have similar chemical properties in their upper horizons. Influence of parent materials on chemical properties of soils formed on basalt and limestone are evident only in the lowest horizons (Heilman and Gass 1974). A substantial proportion of nutrients are in the soil organic layers; even in the deeper soils of southeast Alaska, tree rooting is generally shallow. Ten inches of mineral soil over bedrock appears to be sufficient depth for maximum tree production and site class (Heilman and Gass 1974). Destruction of the upper soil layers is therefore likely to have adverse effects on tree growth.

In summary, it appears that toward the south soils tend to be eper, better developed, and more fertile at greater depth than soils ward the north. From the standpoint of tree establishment and growth, rface organic material and upper soil horizons take on added importance rthward. Recommendations in the literature for seed bed suitability ich involve "mineral soil" should be evaluated carefully; they may not applicable beyond the area in which studies were conducted. The me is true about engineering properties of soils, and practices that e recommended for use in one location may prove to be totally unsuit- le in other areas. A detailed comparison of soil characteristics roughout the hemlock-spruce type would be of great value for the actitioner faced with the prospect of managing diverse soils within e type.

GETATION

Classification

Major habitats within the hemlock-spruce type have been generally scribed, but a comprehensive vegetation classification system for the pe as a whole has not been developed. Limited analyses of plant mmunities have been made in parts of Oregon and Washington (Hines 71, Meurisse and Youngberg 1971, Sharpe 1956, Fonda 1967, Franklin and rness 1973). In British Columbia, Krajina (1965, 1969) and Packee 974a, 1974b) have described ecological forest units. In Alaska, major getative types have been described in general terms[3/] (Dachnowski-Stokes 41, Neiland 1971, Taylor 1932). A thorough analysis of plant com- nities has been made of only one area on the Alaska coast (Worley 77).

Forests dominate the landscape throughout the hemlock-spruce type. st commercial forest communities occur on relatively moist, well- ained habitats with well-developed soils. These habitats cover a nge of soil and moisture conditions as well as climatic differences.

Naturally occurring nonforest habitats are confined primarily to e ocean front in Oregon and Washington where Franklin and Dyrness 973) recognized sand dune and strand communities, tideland communi- es, and herb and shrub-dominated communities. Tide-influenced com- nities are also found in British Columbia and have been described for aska (Stephens and Billings 1967, Worley 1977).

Nonforest alpine communities become common northward as the hemlock- ruce type widens and timberlines lower. Worley (1977) described an pine community in Alaska.

Other interesting habitats may be partially or completely forested. Alaska deciduous shrublands, peatland, spruce parkland, and beach mmunities have been described (Worley 1977), as well as a forest mmunity growing on a thin mantle of till on an active glacier tephens 1969b).

In British Columbia, a narrow band along the outer coast has been scribed in which Sitka spruce forms nearly pure stands, having placed western hemlock and western redcedar because of tolerance to lt spray (Cordes 1972).

[3/] Palmer, L. J. 1942. Major vegetative types of southeastern Alaska. U.S. p. Inter. Fish and Wildl. Serv., Juneau, Alaska. 16 p.

In Oregon and Washington, Franklin and Dyrness (1973) described forested swamps, in which western redcedar or red alder are dominant, along with western white pine, shore pine, Sitka spruce, and western hemlock. Understory tends to be rank, with dense shrub layers.

In Alaska, muskegs consisting of deep layers of peat are common (Dachnowski-Stokes 1941, Neiland 1971, Worley 1977). They support sparse stands of shore pine, Sitka spruce, mountain hemlock, Alaska-cedar, and western redcedar (fig. 3). Poorly drained organic soils supporting noncommercial forest stands of western redcedar, Alaska-cedar, mountain and western hemlock, and Sitka spruce are also common throughout coastal Alaska. Although important from the standpoint of watershed protection, wildlife habitat, and other uses, these sites are not now important for timber production.

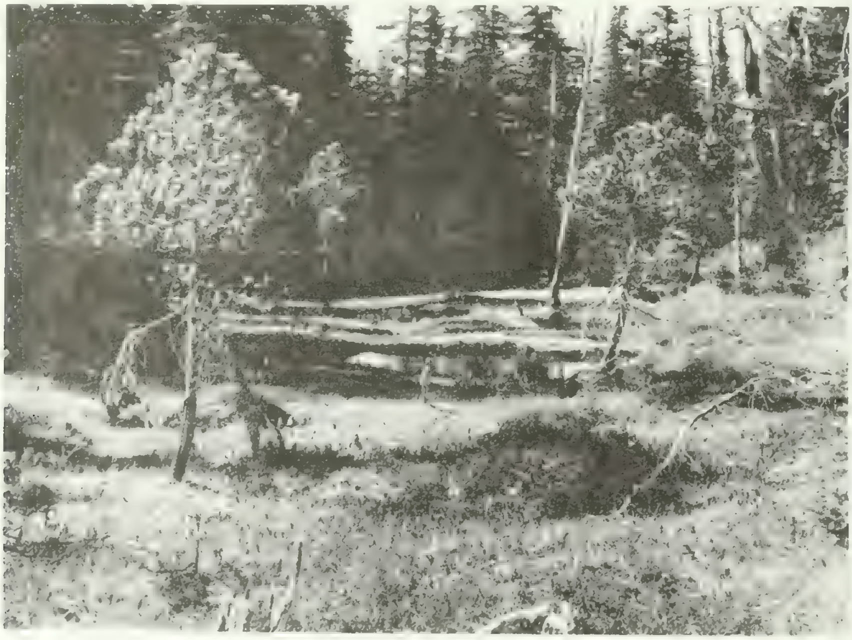

Figure 3.--Shore pine growing on a muskeg or sphagnum bog, Chicagof Island, Alaska.

Forest Composition

The hemlock-spruce type includes some of the finest forests in North America. Old-growth stands contain many extremely large trees, some more than 16 ft (4.9 m) in diameter and over 200 ft (70 m) tall. Productivity of the better sites, as measured by annual biomass or wood production, is among the highest in the world (Briegleb 1940, Fujimori 1971, Munger 1946) (fig. 4). Associated with western hemlock and Sitka spruce in portions of the type are Douglas-fir, western redcedar, and 11 other conifers. There are eight broadleaf trees; black cottonwood, red alder, and bigleaf maple are the most important. Broadleaf trees, however, are far less common than in many forest types.

A number of excellent references are available for identification of trees, shrubs, and other vegetation within the hemlock-spruce type. For the Pacific Northwest area, the five-volume "Vascular plants of the Pacific Northwest" (Hitchcock et al. 1955, 1959, 1961, 1964, 1969) is

Figure 4.--A 160-year-old, even-aged stand of hemlock and spruce on Tuxekan Island, Alaska. Even-aged stands such as this contain prime sawtimber and are far less defective than older, uneven-aged stands.

e of the most complete and detailed. For British Columbia, Hosie's 969) "Native trees of Canada" provides good coverage of tree species. lder and Taylor's (1968) "Flora of the Queen Charlotte Islands" covers scular plants of that interesting archipelago.

The most extensive published flora for use in Alaska, "Flora of aska and Neighboring Territories" (Hultén 1968), includes keys and scriptions for all vascular plants known in the area. For trees and rubs, "Alaska Trees and Shrubs" (Viereck and Little 1972) is an cellent reference. A condensed version for pocket use is also availa- e (Viereck and Little 1974).

The most comprehensive single source of information on the silvical aracteristics of the tree species within the entire range of hemlock- ruce forests is "Silvics of Forest Trees of the United States" (Fowells 965). Range maps for all the major tree species within the hemlock- ruce type are shown in this reference. In addition, more recent maps n be found in the "Atlas of United States Trees" (Little 1971, Viereck d Little 1975). For nomenclature of trees we have followed Little 953a).

Tree species occur in various combinations as a result of many erlapping natural ranges (fig. 5). Within their natural ranges,

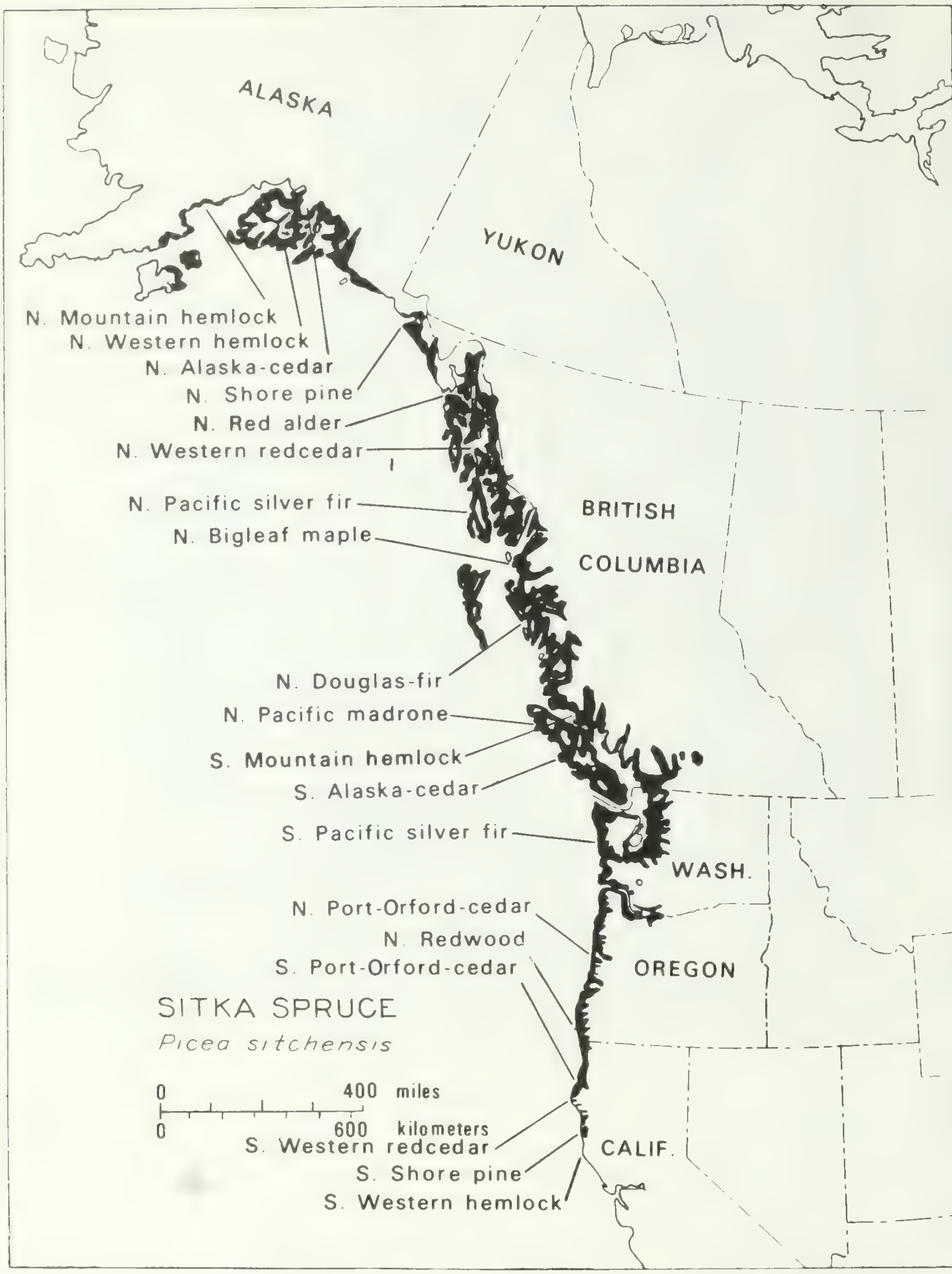

Figure 5.--The Pacific coastal strip showing the range of Sitka spruce and, within it, the approximate range of associated tree species. N and S indicate approximate north and south limits of range.

habitat conditions, history of stand establishment, and successional stage influence forest composition. The tendency within the type for drier, warmer conditions toward the south and east and cooler, wetter conditions toward the north and west helps to explain much of the variation in species composition.

Pacific silver fir becomes an associate north of the Columbia River and extending north through British Columbia. It has a limited range in Alaska, rarely exceeding 1,000 ft (300 m) in elevation. Western redcedar is an important associate at low elevation to 56° latitude where its northern progress is thought to be limited by temperature during the growing season (Gregory 1957b). Alaska-cedar and mountain hemlock occur at elevations well above hemlock-spruce in Oregon and Washington; but with increasing latitude, they occur at lower elevations and become associates of western hemlock and Sitka spruce near the center and northern tip of Vancouver Island. Shore pine is confined mainly to maturing coastal sand dunes in Oregon and Washington but in Alaska may occur up to 1,500-ft (450-m) elevation. It extends north as far as Yakutat. Sitka spruce, which in Oregon and Washington rarely has the opportunity to grow at higher elevations because of low topography along the coast and summer drought farther inland, is found in Alaska on nunataks as high as 4,000 ft (1 200 m) (Heusser 1954).

Toward the western portion of Prince William Sound, mountain hemlock along with Sitka spruce are the most prominent species. Alaska-cedar extends along the coast to Port Wells in Prince William Sound, but other associates drop out along the way. Of all tree species within the hemlock-spruce type, Sitka spruce occupies the most extensive range within Alaska.

The natural ranges of trees within the hemlock-spruce type reflect the interaction of climate and the requirements of the species. For example, hemlock-spruce merges into the Douglas-fir type in areas having a history of pronounced summer drought. Usually there is a narrow transition zone supporting all three species. Within the type, the range of Douglas-fir extends northward only to Gardner Inlet on the British Columbia mainland. Although the species is capable of growing in Alaska (Harris 1971b), its natural range appears to be restricted because of lack of a pronounced fire history farther north (Schmidt 1960).

Another factor affecting tree ranges is the length of time since deglaciation. Movement of tree species as a result of climatic changes is well documented (Heusser 1960, Hultén 1937). Examples can be found with northerly expansion of Pacific silver fir in southeast Alaska (Schmidt 1957, Heusser 1960) and southwesterly expansion of Sitka spruce on Kodiak Island southwestward of the hemlock-spruce type (Griggs 1934). Mountain hemlock and western hemlock also may be moving southwestward in Alaska, but this is not documented.

Understory Vegetation

Young hemlock-spruce forests are typically dense, gradually opening up with age to allow development of a lush understory of shrubs, herbs, grasses, and cryptogams. In open old-growth stands, understory vegetation may be tall and so dense that travel through the forest can be difficult. Species diversity, size, and growth rate of understory plants generally are highest in Oregon and Washington, gradually decreasing northward.

In Oregon and Washington on sites modal in environmental conditions, common understory species in hemlock-spruce forest include *Polystichum munitum*, *Oxalis oregana*, *Maianthemum dilatatum*, *Montia sibirica*, *Tiarella trifoliata*, *Viola sempervirens*, *V. glabella*, *Disporum smithii*, *Vaccinium parvifolium*, and *Menziesia ferruginea*.

On less favorable sites, *Gaultheria shallon*, *Rhododendron macrophyllum*, and *Vaccinium ovatum* are common. On wetter forest sites, the previously mentioned modal species occur, along with *Athyrium filix-femina*, *Blechnum spicant*, *Dryopteris austriaca*, and *Sambucus callicarpa* (Franklin and Dyrness 1973).

In Alaska the more common understory plants include *Oplopanax horridus*, *Vaccinium ovalifolium*, *V. parvifolium*, *V. alaskaense*, *Menziesia ferruginea*, *Rubus spectabilis*, *R. pedatus*, *R. parviflorus*, *Cornus canadensis*, *Dryopteris dilatata*, *Ribes bracteosum*, *R. laxiflorum*, and *Streptopus amplexifolius*.

Cryptogams are extremely abundant throughout the hemlock-spruce type. The Olympic Peninsula is especially noted for mosses, many of which occur as epiphytes on living trees (Pechanec and Franklin 1968, Coleman et al. 1956). Detailed taxonomic and ecological studies have been made on the Olympic Peninsula (Sharpe 1956, Coleman et al. 1956, Harthill 1964). Information on the distribution of cryptogams is also available for the hemlock-spruce type in Alaska (Worley 1970a, 1970b).

Understory vegetation is important for wildlife and for the functioning of the forest ecosystem. Larger plants, such as shrubs, tall ferns, and herbs, often compete directly with tree seedlings for light and growing space. When stands are opened by timber harvest, understory plant species may proliferate and capture the site. Hines (1971) noted that 12 species of shrubs occurred on two plant communities dominated by hemlock-spruce overstory in Oregon (table 2). Several of these, along with tall herbaceous plants and ferns, are important competitors of conifers.

Table 2--A summary of the percentage of plots with shrub species present within two hemlock-spruce communities in Oregon (Hines 1971)

Shrub species	Plant community	
	Hemlock-spruce/ devilsclub-lady fern	Hemlock-spruce/ salal-deerfern
	Percent	
Vaccinium parvifolium	90	100
Menziesia ferruginea	71	90
Berberis nervosa	5	0
Acer circinatum	57	0
Oplopanax horridus	52	0
Gaultheria shallon	19	100
Vaccinium ovalifolium	90	71
Rubus spectabilis	62	48
Rubus nivalis	0	5
Sambucus callicarpa	0	5
Rubus parviflorus	5	0
Vaccinium ovatum	0	19

Forest Succession

Within the hemlock-spruce type, forest succession follows disturbances, such as logging, fire, blowdown, insect attack, landslide, glacial retreat, or uplift from the sea.

Primary forest succession occurs after new exposure of barren land; or example, by glacial retreat, uplift from the sea, formation of stream ırs, or landslide. Initially, little or no vegetation or organic ıtter is present. Soil is poorly developed and may lack a faunal ›pulation.

Secondary forest succession follows disruption of an existing ›rest community rather than by exposure of new land. Blowdown, fire, ıd logging are the most common causes of disturbance. Disturbance is ›ss drastic than with primary succession; and components of the former and (such as live seeds, roots, or entire plants) remain, along with ›cumulated organic matter. Soil may be well developed and may contain large and diverse faunal population.

In Alaska, studies of forest succession have emphasized primary ıccession because the widespread and rapid retreat of glaciers during ıe last 200 years has provided numerous opportunities for study (fig. 6).

igure 6.--Primary forest succession following glacial retreat is common within the hemlock-spruce type in coastal Alaska. Mendenhall Glacier, Alaska.

In Oregon and Washington, opportunities for study of primary succession are largely confined to stream terraces; most studies stress secondary succession. The successional trend after blowdown, fire, or logging on commercial forest land on upland sites tends toward replacement of forbs, shrubs, or alder with appropriate mixtures of Sitka spruce, western hemlock, Douglas-fir, or cedars, depending on latitude, followed by eventual replacement with western hemlock.

Tree species differ in their requirements for moisture, light, ıtrients, heat, and growing space and thereby respond differently to ıe local environment. For example, lodgepole pine, Douglas-fir, and ›d alder roots can grow in dense soils that prohibit growth of Sitka ›ruce, western redcedar, and western hemlock. Pacific silver fir ranks ›tween these two groups (Minore 1969a). Red alder, western redcedar, itka spruce, and western hemlock are more tolerant of shallow water ables than Douglas-fir is (Minore 1970, Minore and Smith 1971). Ranked ›ccording to flood tolerance, western redcedar and lodgepole pine are ›st tolerant; red alder, Sitka spruce, and western hemlock are inter›ediately tolerant; and Douglas-fir is extremely intolerant (Minore 1968).

Tolerance to salt is important for coastal species, and Sitka spruce is much more tolerant of ocean spray than either western hemlock or western redcedar (Cordes 1972). This accounts for the prominent position of spruce on exposed headlands and beaches along the outer coast. In Alaska, spruce is a pioneer species on recently uplifted beaches.

Initial establishment of species depends on seed source, seed bed, soil, moisture, and other factors. In Oregon and Washington, Franklin and Dyrness (1973) recognized two major kinds of seral forest stands in the hemlock-spruce type: (1) coniferous, containing varying mixtures of spruce, hemlock, and Douglas-fir; and (2) red alder or other hardwood. These two distinctive stand types usually occur as a result of site disturbance and seed source. In general, more severe soil disturbance tends to result in earlier successional status of the new stand. Slight disturbance favors establishment of hemlock, and intermediate disturbance favors establishment of Sitka spruce or Douglas-fir. Severe soil disturbance from logging or fire sets the stage for alder establishment, and if a seed source is available, alder will often capture the site.

In Oregon and Washington, alder is concentrated on mesic sites with a history of scarification or fire (Newton et al. 1968). In Alaska, it becomes established on disturbed soil where the duff layer has been removed by logging (Harris and Farr 1974), and on alluvial and colluvial soils lacking a well-developed duff layer.

Throughout most of the hemlock-spruce type, a dense understory of salmonberry may become established beneath alder. Hemlock seldom invades these sites. Sitka spruce will become established but often with great difficulty. If alder is removed, salmonberry tends to replace it and further retard conifer development. Under drier soil conditions, Sitka spruce will become established with the alder, and later, western hemlock; these remain suppressed but gradually overtop and shade out the alder, usually within 40 to 60 years.

In Oregon, toward the southern portion of the hemlock-spruce type, winters are mild and plant growth may continue throughout the year. Here red alder, salmonberry, thimbleberry, vine maple, and large annual plants apparently attain maximum development and play an especially important role in early succession. Dense alder, salmonberry, and thimbleberry are often already established on upland sites, especially where conifer stands have been opened by wind or from other causes. After removal of the overstory, these species proliferate where they are already established and quickly invade disturbed sites. Left untreated, they dominate the site for many years. Douglas-fir appears to be incapable of long suppression beneath alder and is only able to become established in openings where it develops concurrently with the alder (Newton et al. 1968).

Toward the north on sites where disturbance is less or where an alder seed source is not present, mixed stands of Sitka spruce and western hemlock become established along with other conifers. For the first few years, shrubs--such as blueberry, huckleberry, rusty menziesii, elderberry, and thimbleberry--dominate the site. These shrubs resprout from well-developed root systems or grow from seed and at first, grow much faster than conifers. Within a few years, some conifers usually gain dominance but the stand may be poorly stocked and of poor quality.

Tolerance to shade is especially important for establishment of tree species and in determining successional trends. The most tolerant

pecies becomes established beneath an existing stand and usually ecomes the climax species.

Western hemlock is more tolerant of shade than Sitka spruce and ominates reproduction in old-growth forests in Oregon and Washington Franklin and Dyrness 1973), British Columbia (Krajina 1969), and Alaska Taylor 1932). The tolerance of a species tends to vary with the climatic onditions in which it grows. For a given species, shade tolerance ecreases under cooler, wetter conditions and increases under warmer, rier conditions (Krajina 1965). Thus, within the hemlock-spruce type, olerance tends to decrease northward. For example, Sitka spruce is onsidered a tolerant species in Oregon and Washington (Franklin and yrness 1973) but intolerant in Alaska (Heusser 1960). Likewise, estern redcedar, described as tolerant in Oregon and Washington, ehaves as an intolerant species in British Columbia (Schmidt 1955) and n Alaska (Gregory 1957b).

Shade tolerance of the major species in Oregon and Washington ompared with those in Alaska (table 3) suggests that tolerance of arious species may be affected to different degrees under climatic onditions at the extremes of the hemlock-spruce type--some species emaining unchanged, some moving one level, and some moving two levels. t is difficult to tell how much of these differences results from an nadequate method of describing tolerance and how much from actual ifferences in tolerance.

Table 3--Tolerance to shade of major tree species by location within the hemlock-spruce type

Area	Very tolerant	Tolerant	Intermediate	Intolerant
Oregon and Washington[1/]	[illegible]s *amabilis* *Tsuga heterophylla*	*Abies lasiocarpa* *Chamaecyparis lawsoniana* [illegible] *nootkatensis* [illegible] *Sequoia sempervirens* [illegible] *Tsuga mertensiana* [illegible]		*Pinus contorta* [illegible] [illegible] *menziesii* *Alnus rubra*
Alaska[2/]	*Abies amabilis* *Tsuga heteroph*[illegible]	*Abies lasiocarpa* [illegible]	[illegible]	[illegible] *Alnus rubra* *Chamaecyparis nootkatensis* *Thuja plicata*

1/ From Franklin and Dyrness (1973), table 3.
2/ From Gregory (1957b), Schmidt (1955), Heusser (1960); and observations on file at Forestry Sciences Laboratory, Juneau, Alaska.

Alluvial stream terrace sites on entisols in glaciated valleys hould be considered separately for purposes of management and general cological interest. These stream bottomland sites are common throughout he hemlock-spruce type; although plant communities differ by latitude, any of the basic characteristics remain the same.

Best development of these sites is found on the Olympic Peninsula here relatively large seaward-facing valleys, abundant precipitation, nd warm but equable summer temperatures combine to produce what has een popularly called the Olympic Rain Forest (Kirk 1966). These ld-growth forests are dominated by Sitka spruce and western hemlock

and found in a few major river valleys (Hoh, Quinault, Queets, and possibly Bogachiel Rivers). Trees are very large; dominant spruce reach 90 to 130 in (230 to 330 cm) in diameter and over 250 ft (75 m) in height.

Among the distinctive features of these forests, as pointed out by Franklin and Dyrness (1973), are: (1) an abundance of bigleaf maple and vine maple, (2) a conspicuous coverage by epiphytes, (3) abundant nurse logs, and (4) heavy use by Roosevelt elk. The forests are located within the floodway zone of streams. As classified by Bauer (1971), this zone is characterized by braided channels with islands, meanders with point bars, and active processes of erosion and accretion. Gradient varies between 5 and 25 ft per mile (0.9 and 4.7 m/km).

Although these forests are sometimes considered unique to the Olympic Peninsula (Kirk 1966, Sharpe 1956), they are probably best described as variants of what we consider here the hemlock-spruce type (Franklin and Dyrness 1973, Fonda 1974). Western hemlock appears to be the climax species (Fonda 1974), although Sitka spruce behaves as a climax in many ways (Franklin and Dyrness 1973). Feeding by elk on some understory plants, such as salmonberry and elderberry (Sharpe 1956), may be responsible for some unique characteristics of these stream-terrac sites on the Olympic Peninsula. Northward, elk are not present.

Primary forest succession begins on river bars with willows and alder, with dense salmonberry in areas of high soil moisture. This stage gives way later to black cottonwood-Sitka spruce-alder stands. Toward the south, bigleaf maple is an important species, especially on shallow, stony soil. Toward the north, bigleaf maple is lacking but Sitka alder becomes common. Willows and cottonwood are confined largely to mainland valleys. With few exceptions, these species are rarely found on the northern islands.

Early successional stages give way to a Sitka spruce-western hemlock stage as alders, maple, and cottonwood become overtopped. Stands are often open, with dense salmonberry capturing moister areas. Given enough time, western hemlock will come to dominate the site as soils mature. With active stream cutting and meandering, many valley bottom sites may remain in a subclimax successional stage.

Care should be taken with management of alluvial bottom-land sites. Conifer regeneration may be difficult to obtain, as the sites are readily captured by alder and salmonberry and special effort will usually be required to obtain adequate restocking.

Tree Species

In the following pages we look briefly at the major tree species and their ranges, occurrence, and uses. Silvical characteristics of the various species will be discussed further as appropriate.

Western Hemlock

Western hemlock grows along the Pacific coast from northern California to Prince William Sound, Alaska, and is the major species within the hemlock-spruce type (fig. 7). It occurs in dense stands in mixture with Sitka spruce, mountain hemlock, cedars, and other conifers. Tree associates and growth characteristics vary with latitude, soil type, topography, elevation, and stand history.

In Alaska western hemlock is a major stand component on low-site organic soils and is found in stunted or decumbent form on muskegs. At high elevations, it is mainly replaced by mountain hemlock but is often found at timberline. Best development and growth are on well-drained soils in valley bottoms and on lower slopes where it is an important commercial timber resource.

In southeast Alaska, western hemlock comprises 64 percent of the total growing stock volume (Hutchison 1967). Because figures are not compiled by forest type in the Pacific Northwest or British Columbia, a similar comparison cannot be made for those areas.

Until fairly recently, western hemlock was far less valuable than Douglas-fir or Sitka spruce. Now, however, it is becoming more valuable and interest in management is increasing. In Oregon, Washington, and British Columbia, it is used primarily for construction lumber and pulp. In Alaska, its main use is for dissolving pulp, but more of the better quality logs are being sawn into cants and lumber for export.

Figure 7.--Old-growth western hemlock tree near Juneau, Alaska.

itka Spruce

Sitka spruce (fig. 8) is he second most important tree pecies in the hemlock-spruce ype. Its range extends from orthern California to Kodiak sland and the base of the laska Peninsula. Unlike most

Figure 8.--A large Sitka spruce in an old-growth stand being logged on Kosciusko Island, Alaska.

other major tree species within the type, its range is limited to a relatively narrow strip along the ocean, characterized by mild winters, cool summers, and abundant moisture. Sitka spruce requires abundant moisture throughout the year and will not tolerate prolonged summer drought.

In the southern part of its range as far north as northern Vancouve Island, Sitka spruce is restricted to low elevations along seaward-faci slopes; its range extends inland a few miles on alluvial bottom land along streams and on moist, north-facing slopes. In Oregon and Washington, merchantable trees are usually at elevations below 500 ft (150 but extending to 2,000 ft (600 m) where mountains lie close by the sea.

From central coastal British Columbia northwestward, Sitka spruce extends from sea level to timberline. In southeast Alaska, trees to 3,900-ft (1 200-m) elevation have been reported (Heusser 1954). Maximum elevation of merchantable trees is about 1,500 ft (450 m) on Prince of Wales Island, Alaska, and gradually lowers to 800 ft (250 m) or below on the tip of the Kenai Peninsula.

Total growing stock volume of Sitka spruce within the hemlock-spruc type has been estimated at 18.4 billion ft^3 (0.52 billion m^3)--63 percer in Alaska, 26 percent in British Columbia, and 11 percent in Oregon and Washington. In southeast Alaska, Sitka spruce is the second most abundant timber species, comprising 28 percent of the growing stock volume on commercial forest land (Hutchison 1967).

In Alaska and British Columbia, most of the better grades of Sitka spruce logs are sawn into cants or slabbed for export. Lower grade logs are used for pulp.

Western Redcedar

Western redcedar (fig. 9) is an important component of the hemlock-spruce type. Its range along the coast extends from northern California northward to southeast Alaska. Its northern range is rather sharply defined along the northern and western shores of Sumner Strait on Kupreanof and Kuiu Islands and extends to the vicinity of Petersburg on Mitkof Island (Andersen 1953). Temperatures during the growing season mainly determine the limits of its range (Gregory 1957b) but planted trees are capable of growing at least as far north as Juneau, 120 mi (190 km) north of the species known natural range (Harris and Farr 1974).

Within the hemlock-spruce type, western redcedar is found on poorly drained organic soils, often over hardpan, and on shallow soils over bedrock. Nearly pure stands may develop on the poorer sites, and more often mixed stands develop on the better sites. Best growth occurs on productive, well-drained sites, but on these sites cedar has difficulty competing with western hemlock and Sitka spruce and so is seldom found. In Alaska it is often found in stunted form on muskegs.

Figure 9.--An old-growth western redcedar. Maybeso Valley, Alaska.

In Oregon, Washington, and British Columbia old-growth western rdcedar is in demand for lumber, shakes, and shingles. Younger trees fom even-aged stands are used for poles.

In Alaska, quality is generally lower than farther south. Until afew years ago, there was little demand for the species in Alaska. Sands with a high percentage of cedar were not logged, and cedars ecountered on clearcut areas were felled but often left in the woods. Nw, however, good quality western redcedar logs are second only to Aaska-cedar in value. Most production is exported to Japan as round lgs or rough cants. There is increasing interest in cedar pole poduction. No attempt is now being made to manage stands specifically fr growth of western redcedar.

uglas-fir

Douglas-fir is a common associate in the southern portion of the wstern hemlock-Sitka spruce type, becoming especially important on dier sites inland from the beach (fig. 10).

Douglas-fir ranges along the Pacific coast from northern California t northern Vancouver Island and on the British Columbia mainland nrth to the vicinity of Kemano. Two varieties are recognized, but oly the typical coastal green variety (*menziesii*) occurs within the hmlock-spruce type.

Because of its value, resistance to damage by the white pine weevi and the availability of planting stock, Douglas-fir often has been planted in hemlock-spruce areas in Oregon, Washington, and southern British Columbia. The result has been a slow conversion from hemlock-spruce to Douglas-fir.

Alaska-cedar

Alaska-cedar occur in the hemlock-spruce type from Knight Inlet (about 51°N latitude), British Columbia (Perry 1954), northward and westward to Prince William Sound. It may be found from sea level to timberline (fig. 11).

Figure 10.--Old-growth Douglas-fir, Whatcom County, Washington.

Figure 11.--An old-growth Alaska-cedar. Cape Fanshaw, Alaska.

In coastal Alaska, distribution of Alaska-cedar is scattered, bot on the mainland and on many of the islands. The species can be found in nearly pure stands but occurs more often in scattered groups or individually in mixture with western and mountain hemlocks, Sitka spruce, shore pine, and western redcedar (Harris 1970). It is found as far north as Wells Bay in Prince William Sound (Viereck and Little 1972).

Best development is on thin organic soils over bedrock or occasio on deep, well-drained soils. On the better sites it has difficulty

ompeting successfully with western hemlock and Sitka spruce and is seldom ound. It is a common component of scrub stands on organic soils and ften occurs in stunted or shrublike form on muskegs.

The wood is aromatic and highly resistant to decay. Until recently, here was little demand for Alaska-cedar from southeast Alaska, and rees felled during clearcutting operations were left in the woods. ow, however, logs command top prices and high-quality trees are ought for harvest. The wood is prized in Japan, where much of the roduction is sent (Harris 1971a).

Little is known about the silviculture or management of Alaska-cedar; ntil recently no attempt was made to manage the species. Now, however, ore interest is developing in planting of Alaska-cedar on high elevation ites where regeneration of other conifers has proved difficult, especially in British Columbia where experiments with container-grown seedings are now being conducted (British Columbia Lumberman 1974). Although not a major commercial species, the wood is very valuable; more ttention should be given to assuring its proper management in coastal laska.

Iountain Hemlock

Mountain hemlock (fig. 12) occurs in the hemlock-spruce type from orthern British Columbia to Cook Inlet, Alaska, although its range

Figure 12.--Mountain hemlock near timberline. Harbor Mountain near Sitka, Alaska.

outside the hemlock-spruce type extends south to California and east to western Montana.

Mountain hemlock extends farther west and north than western hemlock, gradually replacing western hemlock as a major species on the Kenai Peninsula, Alaska. There it is able to survive more continental climatic conditions (less humid and greater temperature extremes) than other coastal conifers (Heusser 1960).

At lower elevations in southeast Alaska, mountain hemlock commonly is found on the poorer sites on organic soils. It is a major component along with western hemlock, cedars, shore pine, and Sitka spruce on noncommerical forest land fringing muskegs and often is found on muskegs in stunted or prostrate form. Near timberline, mountain hemlock is a major component of forest stands along with Sitka spruce, and it is often found in prostrate form on alpine meadows above timberlin

Growth tends to be slower than that of western hemlock, even on the better sites, and it does not grow so large. Occasionally it occurs on good sites along with western hemlock and Sitka spruce. Best development is on well-drained soils.

Little attempt is made to manage mountain hemlock. As logging proceeds onto poorer sites and higher elevations, mountain hemlock will become a more important timber resource.

Alders

Three species of alder occur within the hemlock-spruce type. Red alder is found from California northward to the vicinity of Yakutat, Alaska. Sitka alder is found from northern British Columbia northwestward throughout the spruce-hemlock type in northern British Columbia and Alaska. Thinleaf alder has a restricted range along the coast in southeast Alaska (Viereck and Little 1972).

Sitka and thinleaf alders tend to have shrublike forms with multiple stems and rarely exceed 30 ft (9 m) in height. In contrast, red alder usually has a single, well-defined stem and may reach heights of over 100 ft (30 m).

In Alaska, alder is commonly found along beaches and streams, on avalanche tracks and landslides, and as a pioneer with Sitka spruce, willows, and cottonwood on land recently exposed by glacial outwash, retreat, or land uplift. Alders are also common on roadsides, landings, and wherever mineral soil has been disturbed (fig. 13). Alders are intolerant of shade, and in successional stands alder is usually shaded out after 40 to 60 years as it is overtopped by Sitka spruce. Red and thinleaf alders are seldom found above 1,000-ft (300-m) elevation, but Sitka alder may grow above 3,000 ft (900 m) (Harris and Farr 1974).

Organisms in root nodules on alders are able to fix atmospheric nitrogen and so improve soil fertility (Bond 1970, Tarrant 1964a, Tarrant and Trappe 1971). Additional benefits result from effects on soil chemistry, microbiology, and nutrient cycling (Lu et al. 1968, Zavitkovski and Newton 1971). Because of this, alder is able to grow on infertile soils and stimulate the growth of adjacent plants (Lawrence and Hulbert 1950).

Figure 13.--A young stand of red alder established following logging of a spruce-hemlock stand on an alluvial valley bottom site. Admiralty Island, Alaska.

Only red alder is of commercial importance. The wood is excellent r pulp and furniture (Plank 1971). It is the most important hardwood ecies in the Pacific Northwest; some 250 million board feet were gged in 1970 (Lawton 1972). It is also becoming an important pulp ecies. Recent changes in economics and technology have made possible ole-tree chipping of alder in the woods, including stems, branches, rk, and leaves. Bark is reported to be easily assimilated in the lping process compared with thicker softwood bark (Western Timber dustry 1975). Red alder is an efficient converter of solar energy, d biomass from alder could supply energy for human use in the ture (Smith 1978b).

In Alaska red alder is used for smoking fish and for carving but herwise is not yet used commercially.

Red alder is only occasionally being managed as a timber resource d is still considered a weed by some forest managers. Efforts are ing made to control the species where it competes with Sitka spruce d other conifers. Interest in red alder has, however, increased eatly in recent years (Trappe et al. 1968, Briggs et al. 1978). d alder will likely increase in value as a commercial species.

Bigleaf Maple

Bigleaf maple occurs in the hemlock-spruce forests from Califo to northern British Columbia (fig. 14). Repeated searches have failed to locate specimens in Alaska, despite early reports of its occurrence (Viereck and Little 1972). Lack of moisture apparently limits its range to the south, and low temperatures are limiting northward. East of the hemlock-spruce type, the species occurs inland to the Sierra Nevada and Cascade Range.

Optimum growing conditions are found in the humid climate of western Oregon. Best development is on deep alluvial soils near streams, although it also occurs on a variety of soils from deep loams to thin soils on rocky slopes.

Seeds of bigleaf maple are eaten by small mammals and birds; in the sapling stage, bigleaf maple provides browse for black-tailed and mule deer and for elk.

Maple syrup has been made from the sap of bigleaf maple. Past experience has shown that annual sap flow averages from 3 to 6 gal (11 to 23 liters) per tree; about 35 gal of sap are required to make 1 gal of syrup. Although there are no records of commercial production, syrup production as a hobby or small enterprise would seem feasible (Ruth et al. 1972).

Figure 14.--A stand of bigleaf ma on bottom land along the Santiam River, near Jefferson, Oregon.

Black Cottonwood

Within the hemlock-spruce type, black cottonwood is found primarily in the major river valleys and on outwash plains, usually in association with Sitka spruce, willows, and alders. In Oregon and Washington, it is common bordering tidal flats and channels all along the coast (Franklin and Dyrness 1973).

Black cottonwood is found primarily in the major river valleys and outwash plains on the southeast Alaska mainland (fig. 15). Major occurrences are in the Unuk, Chickamin, Stikine, and Taku

River Valleys, in many valleys in the vicinity of Lynn Canal, and on glacial outwash plains near Yakutat. A few stands occur in island valleys in the vicinity of Sitka. Occasional trees can be found in scattered locations on the islands near present or former habitations where they may have been planted. Black cottonwood has been used for pulp and furniture in Oregon. In Alaska, it has been logged along with Sitka spruce and western hemlock in clearcutting of primary stands. The market has not, however, been stable and the species is not consistently sought for harvest. The wood has been tested in Alaska for use as dissolving pulp, but at present there is no market. The tree is often planted as an ornamental because of its fast growth and handsome form; however, the wood is brittle, and exposed trees are subject to wind damage.

Figure 15.--Few black cottonwood are as large as this 10-foot (3-m) diameter specimen located near Klukwan, Alaska.

INITIATING TIMBER MANAGEMENT

In the northern portion of the hemlock-spruce type, most of the forests have never been logged. Almost everywhere else, someone has gone before--some plans are made, some roads are in, some timber cut--and the manager must go from there. In Alaska and parts of British Columbia, the manager can start from scratch, fortunate enough to have information and experience from farther south and from other forest types as guides.

In southeast Alaska, old-growth stands occupy about 87 percent of the productive forest land area (Hutchison and LaBau 1975). The current approach on National Forest land in coastal Alaska is to develop management plans, based on recommendations from multidisciplinary teams, that integrate all aspects of forest protection and use. The result places many restraints on road construction and harvest cutting.

Our discussion is organized to stress silvicultural practices. Restrictions needed to protect basic soil and water resources are described where they tie into the silvicultural practice under discussion. Special sections on forest protection and multiple use are presented later.

LOGGING PLANS

Moving into an undeveloped drainage to make harvest cuttings needs careful advance planning. The initial road system serving areas to be cut may go through intervening areas of green timber reserved for later harvesting. This road system should be designed to serve not only the cuttings of the first entry but also the reserve areas. Otherwise, the reserve areas may not be logical logging units and the roads may not serve them efficiently.

A common procedure is to make a tentative layout of all roads, landings, and cutting boundaries on aerial photos or topographic maps of the area. These are taken into the field where obstacles to application of the plan can be spotted during reconnaissance. The plan is altered to fit conditions on the ground, and a final pattern of roads and landings to serve the entire area is developed. This becomes the forestry-logging plan for the area (Ruth and Silen 1950).

The areas to be harvested during the first entry should be identified as one of the last steps in the planning process--after the planning team is thoroughly familiar with the area. The most decadent stands should be harvested first and converted to vigorous young stands. They are best identified when the forestry-logging plan is being checked in the field. Only the roads to serve these particular areas are designated for initial construction.

Sophisticated planning is needed when skyline yarding systems are used. Burke (1975a, 1975b) described one planning technique particularly adapted to skylines; desk top calculator, plotter, and digitizer facilities are used to analyze alternate skyline lead paths. Projected skyline roads are then plotted on a topographic map and coordinated with a proposed road system which can be evaluated with the same equipment. Tentative plans can be plotted by the equipment and viewed in perspective--as one would look at roads, landings, and cutting boundaries plotted on a relief map.

Whatever the planning system used, it is critical that roads and landings be coordinated for maximum overall efficiency and that the road system serve the reserve areas to be harvested later.

Many factors besides the coordination of road spacing and yarding must be considered in preparing a forestry-logging plan. Foremost is protection of the basic soil resource. Roads and landings must not cause erosion. Generally, this means locating them away from streams. Stream crossings should be limited, made where disturbance will be minimum, and carefully planned to avoid stream siltation.

The selection, layout, and operation of the yarding system must be controlled to provide an appropriate level of disturbance to the site, enough to facilitate regeneration of the stand but not enough to cause loss of soil. In many cases the high-lead system with logs dragged on the ground may be used. Care must be taken with downhill yarding because high-lead skid trails tend to concentrate runoff and may lead to soil erosion. Less disturbance will result from grapple yarding which normally lifts one end of the log free of the ground. In other cases, both ends of the log should be lifted free. At the other extreme the disturbance caused by rubber-tired skidders or crawler tractors may concentrate runoff and lead to erosion. Where soils are poorly developed, heavy disturbance often leads to serious damage to the soil and invasion by competing vegetation.

Another important factor is public use, particularly recreational use on public land. This affects such items as road standards, size and arrangement of harvest cuts, scenic strips along main waterways, and buffer strips along streams. Arrangement of cuttings to minimize wind damage and facilitate fire protection is an important factor to be discussed in detail later.

Adjustments in the forestry-logging plan to meet wildlife management objectives may be important, such as leaving areas uncut to protect eagle nesting trees or deer winter range.

Preparation of the forestry-logging plan and initial development of a road system for a hemlock-spruce drainage mainly determines the future character of that area. If roads are located for timber access alone, they may not be in the best location for recreational use. The converse also is true. Land use objectives should be carefully determined in advance. Timber harvesting determines the distribution of age classes available for the next rotation, so effect of the initial plan extends indefinitely into the future. The many undeveloped hemlock-spruce areas in Alaska provide an excellent opportunity to prepare comprehensive forestry-logging plans that consider all land use objectives.

ROADS

Location, construction, and maintenance of roads are important activities of the land manager. Roads are needed for access but are costly to build and maintain and can be a source of erosion, sedimentation, and other adverse effects on the environment. Roads needed for timber harvest usually range from 5 to 7.5 mi/mi^2 (3.1 to 4.7 km/km^2) of land area; but more or less may be needed, depending on average yarding distance. Skylines reach out longer distances and require

less road than conventional high lead or grapple yarding systems (Burke 1975a, 1975b). In special situations helicopters may be used so that fewer roads are needed. Greater road mileage is required where clearcuts are small or where the shelterwood or selection system is used and logs must be yarded through standing timber. For example, small clearcuts of 10 acres (4 ha) or less or use of the selection system may require construction of 7.5 mi of road per square mile (4.7 km/km^2) cut, although clearcuts of 100 acres (40 ha) might require only 6.3 mi/mi^2 (3.9 km/km^2) (Staebler 1971).

Roads also take land out of tree production. Silen (1953) examined roads on a steep Cascade Range watershed and found 9.8 percent of the area disturbed by construction of roads and landings. This area was not all lost to timber production because some of the disturbed area will reforest and roots and crowns will encroach under and over road and landing areas. Production loss was estimated to be 4.1 percent.

The wider the interval between roads the longer the yarding distance and the higher the yarding cost. The most economic road spacing for harvesting a timber crop is when the combined costs of road construction and yarding are a minimum. If only a single harvest of the timber is considered, a cost analysis would indicate minimum road construction and relatively long yarding distances. If yarding costs for thinnings and harvest cuttings during future rotations plus costs for administration, fire protection, and other values of roads are included in the analysis, results will indicate closer spacing of roads and shorter yarding distances. Roads have some disadvantages too. Besides construction and maintenance costs, there are added risks of erosion and mass soil movement, land taken out of production, and adverse effects on the environment. These too must be included in the analysis. Road location should be based on capabilities of the yarding equipment to be used. Yarding techniques have changed over the years, however; and planning a permanent road system runs the risk that a different yarding technique will be used in the future and the road will not be suitably located for it. A common practice in Oregon and Washington has been to locate roads on the outer edge of benches where cables can be used to reach down the steep slope and yard logs up from below and tractors can be used to yard logs down the moderate slope of the bench to the road. With increasing emphasis on minimizing soil disturbance, tractors and rubber-tired skidders often are avoided in favor of cable yarding which usually works best for yarding logs uphill. In Alaska, roads are usually built near valley bottoms and logs are yarded both uphill and downhill. Grapple and skyline yarding, which are gaining rapidly in popularity, require a concave yarding profile to provide lift for the logs. Careful road location can do much to increase the proportion of yarding areas with suitable configuration, but the result will be a different road system than one planned entirely for high-lead yarding.

Intensive management requires good access, so trends in road location are toward closer spacing. Most areas now being logged have never been thinned and a primary objective of road location is removal of the natural stand by clearcutting. There are no residual trees in the way and yarding distances can be long. The next rotation, however, will be managed more intensively. Thinnings usually will be needed, and logs will have to be yarded through a residual stand. This will

equire shcrter yarding distances. In general, where more intensive anagement is anticipated, it is best to opt for closer road spacing han that needed for large-scale clearcutting.

Whatever the road spacing selected, it is important to minimize oad length. A systematic road pattern will provide access with less oad mileage than a random pattern (Burke 1975b). Silen (1955) tudied efficient road patterns in a watershed similar to many in the emlock-spruce type and recommended that a high proportion of a rainage be served by parallel road levels spaced at the economic nterval. There should be a minimum number of roads that climb etween levels. When two roads fork, it is desirable that the fork e in an area where the roads can separate quickly and each serve its ull complement of timber. It is inefficient to have two parallel oads closer than the road interval that is most economical.

Road construction usually has a greater effect on stability and rosion of soil than any other forest activity. Building a road cross a steep side slope changes drainage patterns, undercuts the phill slope, and if waste material is sidecast, adds overburden to he lower slope. Mass soil movement may result. Full bench construcion is best on unstable slopes with waste material hauled away and eposited on stable areas. Roads should be adequately crowned and itched and surface runoff distributed through culverts to the forest loor below the road. In Alaska almost all roads need to be rock urfaced because of the wet climate and fragile soils (fig. 16).

Figure 16.--A typical rock-overlay logging road under construction on Prince of Wales Island, Alaska.

Even so, log hauling causes some muddying of the road surface. The mud gets into ditch water and eventually to the downhill slopes. In Oregon and Washington some main access roads have been paved to reduce maintenance costs and minimize runoff of muddy water. It is best to locate roads and surface-water culverts so the water flows through a filtering area of forest floor material before entering a stream (Sommer 1973, Swanston and Dyrness 1973). Culverts placed in streams with fish populations must allow fish passage. Open-bottom structures may be preferred over pipes because there is less chance of creating an impassable waterfall at the lower end of the culvert (USDA Forest Service, Alaska Region 1977) (fig. 17).

Figure 17.--These culverts were improperly installed above the streambed and will not allow upstream passage of resident coho and trout. Kuiu Island, Alaska, 1975. (Photo, courtesy of Alaska Department of Fish and Game.)

An objective of location and design of roads should be to minimize construction and maintenance costs, exposure of mineral soil and resulting erosion problems, the visual impact, and land taken out of production. This may be accomplished by avoiding steep slopes, reducing depths of cut and fill, and generally minimizing the volume of excavated materials. Road standards should not be higher than needed for timber hauling and other planned uses.

HARVESTING EQUIPMENT

Early day yarding of hemlock and spruce was mostly done by large steam skidders; logs were transported by railroad in Oregon and Washington and by rafts in British Columbia and Alaska. Use of trucks

for hauling logs began before World War II. Now almost all logs are moved to the mills by truck in Oregon and Washington and by truck to transfer points for further barging or rafting to the mills in British Columbia and Alaska.

A trend toward tractor yarding on moderate slopes, readily apparent in the Douglas-fir type, has not developed in the hemlock-spruce type because of soil conditions. Yarding with crawler tractor and rubber-tired skidders now is avoided on many areas because of wet soil and associated problems of soil compaction and because skid roads change the drainage pattern and may cause soil erosion. Currently, cable yarding is the rule and ground equipment the exception. A high-lead system with portable spar; main, haulback, and straw lines; butt rigging; and chokers is still in general use, especially in Alaska (fig. 18).

Grapple yarding, in which logs are grasped with a mechanical grapple and yarded perpendicularly to the road with a running skyline system, is currently gaining wide acceptance, especially in Oregon and Washington (Sommer 1973). Yarding distances usually do not exceed 800 feet (240 m), similar to most high-lead yarding.

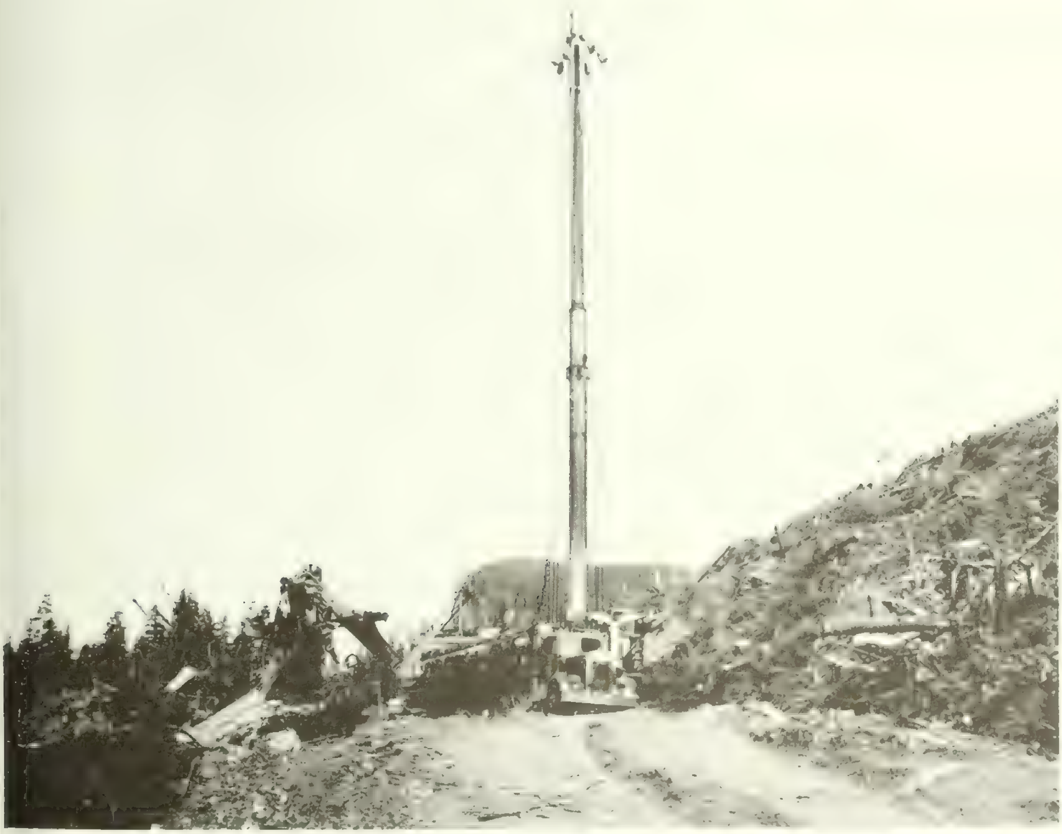

Figure 18.--A high-lead logging operation using a portable steel spar, Tongass National Forest, Alaska.

With grapple yarding most logs come in with the front end lifted clear of the ground. There is much less disturbance of forest residues and ground vegetation and exposure of mineral soil than with high-lead yarding. This reduces erosion potential and damage to advance regeneration but may not expose enough mineral soil for seedling establishment.

Grapple yarding may be done at night, with floodlighting of the yarding area and the landing. Many operators in Oregon and Washington run two shifts to speed production during summer months and to better utilize equipment. One loading shift usually can load logs from two yarding shifts (Burke 1972).

Skyline yarding systems are used in special situations, such as areas of very steep slopes or erodable soil where road construction and site disturbance must be held at a minimum. Skylines can reach out the long yarding distances required. They can lift one or both ends of a log free of the ground during yarding, an increasingly common contract requirement. Logs may be suspended for yarding across streams and streamside leave strips. Skylines may be used for overstory removal with minimum damage to the understory. Those with lateral yarding capability may be used for shelterwood harvesting or thinning (Carson and Jorgensen 1974, Mann 1977).

Helicopter and balloon yarding have been used experimentally in the hemlock-spruce type. They offer alternatives for very long yarding distances or where roads should not be built.

SILVICULTURAL SYSTEMS

Almost all hemlock-spruce harvest cuttings have been by the clearcutting system although any of the four basic silvicultural systems--clearcut, seed tree, shelterwood, selection--or various combinations may be used.[4/] Except for problems of competing vegetation to be discussed later, regeneration can be attained with any silvicultural system or combination of systems. The manager's main focus, therefore, is on economics, future growth and yield, and integration of timber harvest with other forest values.

A basic objective always is to protect soil, water, and related resources. It would be shortsighted to harvest a particular timber crop in any way that would jeopardize production of future crops on the area. If protecting these resources makes logging costs prohibitive harvesting should be delayed until economic conditions change or new technology is developed.

Probably it would be difficult to design a system that would do more than delay establishment of tree seedlings. The usual problem is too much regeneration, leading to costly precommercial thinning or, without this, to overstocked stands (fig. 19). Where possible, harvest cutting techniques should be modified to limit regeneration, but it may be best to aim for extra seedlings as insurance and to encourage selection of seedlings through early thinning or natural competition. An alternative is to strive for the desired number and, if openings occur, fill in by planting. In any event it seems best

[4/] For definitions of silvicultural terminology, see Ford-Robertson (1971).

Figure 19.--Natural regeneration of western hemlock-Sitka spruce is often too dense; 10 years after clearcutting, this stand contained approximately 15,000 trees per acre (37,000/ha).

o strive for a postlogging environment that will limit the number of eedlings rather than one that will be ideal for seedling establishment.

Inefficient use of growing space in hemlock-spruce areas can ccur in several ways. Foremost is the preponderance of climax tands in northern parts of the range; net growth of a climax stand s zero and near-climax stands not much more. Numerous areas are ominated by unwanted vegetation. Other areas have too many or too ew trees; having too many distributes growth to many small stems and aving too few leaves openings in the stand. Openings will eventually egenerate, but the delay causes a loss of production.

Silvicultural systems may be selected to maximize timber production, ut many other objectives are possible. Managing stands in recreation reas, maintaining or improving the scenic beauty of the forest, rotecting watersheds and streams and providing or maintaining forest tands for wildlife are important considerations in many areas.

Whatever the objectives of a proposed silvicultural system, t is important that they be fully understood. The silvicultural ystem adapted must be in harmony with the goals of the landowner. or example, the owner of a small acreage may wish to maintain recreaional values and so might favor the selection system. The industrial wner who has timber production as a main goal would usually favor learcutting and even-aged management. Most public ownerships have ultiple objectives, and various zoning systems are used to identify ominant-use categories. The basic silvicultural systems will be iscussed here, primarily in terms of how they meet timber management

objectives. Invariably there will be multiple and usually conflicti objectives. Some of these are discussed in the section on multiple use. The forest manager must make proper trade-offs and write the silvicultural prescription that will provide the best overall result

SHELTERWOOD SYSTEM

The basic characteristic of the shelterwood system is establishment of a new crop before completion of the preceding rotation; this provides an overhead seed source and overstory protection during seedling establishment. Hemlock and spruce lend themselves admirabl to shelterwood cutting because both readily become established under a forest canopy (fig. 20). Shelterwood cuttings resemble heavy thinnings and use of this method logically follows a series of comme cial thinnings in immature stands. The classical shelterwood prescr tion involves three kinds of cuttings: (1) *Preparatory cuttings* whi stimulate seed production and decomposition of humus on the forest f (2) *seed cuttings* which let in more light and prepare the seed bed, (3) *removal cuttings* which release established seedlings (Smith 1962

Figure 20.--Natural regeneration coming in under shelter of a Sitka spruce-western hemlock overstory. Cascade Head Experimental Forest, Oregon.

An exploratory study of shelterwood cutting on the Oregon coast serves as an example in hemlock-spruce (Ruth 1967a). A 104-year-old stand was thinned about 20 percent, leaving about 76,000 bd ft per acre (360 m^3/ha). The stand had not been scheduled for harvest cutting, and initially this cut was considered an improvement thinning to take out dead, dying, and defective trees; however, hemlock and some spruce seedlings promptly became established under the stand, so a decision was made to call the thinning a seed cut in the shelterwood system and follow through with removal cuttings.

The seedlings grew well the first few years, then slowed as the overstory canopy closed. Numerous spruce and some hemlock seedlings began to die. Nine years after the thinning, when the understory was 51 percent stocked, an additional 27,000 bd ft per acre (130 m^3/ha) was removed from the overstory, leaving a crown closure of about 50 percent. The logging operation reduced stocking to 35 percent, but during the next three growing seasons it increased to 60 percent. Then at this 12-year point, the area was split in half and each half reated separately. They had similar topography and aspect.

On the north half, three more seasons brought stocking up to 4 percent with seedlings up to 8 ft (2.4 m) tall. There were thousands of seedlings per acre. Complete removal of the overstory using crawler ractors reduced stocking to 55 percent. This was a reasonable amount ad distribution been better; but there were too many seedlings in ost areas, and a badly disturbed area around the landing had too few. n general the 1st year, released seedlings had poor vigor and a ellow appearance, apparently from abrupt exposure to the sun. At irst, the area looked much like a normal clearcut, but the established eedlings recovered quickly and soon hid the stumps from view. The anding area was slowest to recover.

On the south half, three additional growing seasons brought tocking up to 73 percent and seedlings up to 8 ft (2.4 m) tall. A wo-stage overstory removal was prescribed. The first stage was ompleted, during the 15th year after the first thinning, by removing 3 percent of the overstory. This reduced stocking to 67 percent. At ast measurement, stocking again was increasing and understory trees ere up to 20 ft (6 m) tall. The stand still is esthetically attractive. he next objective will be to remove the remainder of the overstory ith minimum esthetic impact and with some control over stocking in he new stand.

This exploratory study showed that shelterwood cutting resulted n establishment of a new hemlock-spruce stand, but overstocking was a roblem. The overstory was too dense to maintain spruce in the understory. eedlings suffered shock from abrupt overstory removal. The study also howed that the shelterwood system offers great flexibility in that he overstory can be either removed promptly after seedling establishment r left for several years to take advantage of changing market conditions r to grow understory seedlings to a desired height.

Another study in an unthinned 60-year-old hemlock stand in western ashington also showed overstocking to be a problem (Williamson and uth 1976). This was a three-cut shelterwood with a seed cut and two emoval cuts. There were 12 cutting intensities, leaving basal areas anging from 235 ft^2 to 38 ft^2 per acre (54 to 9 m^2/ha).

Before the seed cut in 1960, the stand was stocked with an avera of 2,220 advance regeneration seedlings per acre (5,480/ha). The first cut destroyed many of these, leaving an average of 650 seedling per acre (1,600/ha). More subsequently died from logging damage and natural mortality so that only 280 per acre (690/ha) were left 2 year after the removal cut in 1971. During this time, postlogging regener tion was prolific and there were 18,500 seedlings per acre (45,700/ha by the final measurement in 1971. Response varied by cutting intensi but in all cases gross overstocking occurred (fig. 21). Eleven years after the regeneration cut and immediately after the harvest cut, pos logging regeneration averaged 4.6 ft (140 cm) in height.

Figure 21.--Eight growing seasons after the first cut and just before the final cut, regeneration was dense. Average height of tallest seedlings on milacre plots was 4.0 ft (1.2 m), Hemlock Experimental Forest, Oregon.

The long conversion period in this study allowed time for seedl to grow above stump height before removal of the final overstory; th helped to maintain a forested appearance. For seedling establishmen alone, the period could have been shorter. For example, under the most open shelterwood, it may have been better to remove all the overstory 4 years after the seed cut rather than just half. There were 6,400 seedlings per acre (15,800/ha) at that time. Waiting 4 more years with an overstory seed source aggravated the overstocking

With a short conversion period, dense overstories also held down numbers of seedlings. The two most dense overstories of 210 and 235 ft^2 per acre (48.2 and 54.0 m^2/ha) had an average of 3,200 seedlings per acre (7,900/ha) in the understory 4 years after the seed cut. Logging half the overstory, plus a year of growth, left the seedling count the same. In 4 more years it increased to 16,500 per acre (40,800/ha). Logging all the overstory at one time might have reduced the seedling count to a more desirable number. Dominant seedlings ranged from 6 to 15 ft (1.8 to 4.6 m) tall on the treatments with low overhead density. Heights were progressively shorter as density and shade increased.

These studies suggest that overstocking of regeneration can be expected with the shelterwood system. Providing an overhead seed source and protective shade improves the environment for seedling establishment, but growth rate of seedlings is slower under shade.

Damage to the residual stand can affect growth and mortality during the conversion period, and decisions should be made on how much effort to expend to minimize losses. With a short conversion period, there is little time for decay to become established and spread, so most volume loss will result from direct physical damage. A long conversion period runs the added risk that decay from stem or root damage will reduce growth and yield.

Many hemlock-spruce stands are stocked with advance regeneration prior to clearcutting, and enough seedlings survive the logging operation to form a new timber stand. These cuttings have been classed as clearcuttings but actually meet the definition for shelterwood cutting in that regeneration is established before removal of the overstory. They might be termed accidental or unplanned shelterwoods. If the seedlings become established under an unthinned stand and the stand conversion is accomplished with one cutting, this could be called a one-cut shelterwood--certainly the system in it simplest form. If a mature stand has been commercially thinned prior to the final cut, the last thinning might be thought of as a seed cut and the stand conversion as a two-cut shelterwood.

It appears that whether a harvesting system is clearcutting or shelterwood cutting is partly a matter of definition and whether or not the establishment and utilization of advance regeneration were part of a silvicultural system. Whatever the terminology, the presence of advance regeneration is increasing rapidly with the spread of commercial thinning in hemlock-spruce stands. Increasing use of the last commercial thinning as a seed cut to encourage regeneration is a logical development.

Residues in shelterwood areas generally are left unburned because danger of fire under the shade of a residual stand is low. It increases after overstory removal but soon decreases again as seedlings overtop residue material and shade it from the sun. If fire danger warrants, residues not in contact with the soil may be lopped and scattered to increase moisture content and speed decay. Extra fire protection may be provided if necessary.

Residues from inital cuts may be piled in the larger openings and burned. Hand piling usually is preferred over machine piling because heavy machines are limited to gentle slopes, may compact the soil, damage established regeneration, damage roots of the residual stand, and expose mineral soil to erosion.

Controlling Species Composition

The shelterwood system may be used to control sunlight reaching the forest floor and thus provide some control of species composition in the regenerating stand. Deep shade favors hemlock, moderate shade permits addition of spruce, light shade permits establishment of Douglas-fir and red alder (Ruth 1967a).

Under a forest canopy, the environment is cool and moist, and organic seed beds, in addition to mineral soil, are satisfactory for seedling establishment. Minore (1972) examined regeneration under hemlock-spruce stands near the Oregon coast. In the deep forest with less than 10-percent sunlight reaching the forest floor, seedlings were found on rotten logs but not on the duff-covered forest floor. Almost always they were pure hemlock. With 10- to 40-percent sunlight, both hemlock and spruce occurred on both logs and the forest floor, but both were taller on the logs. With 40- to 60-percent sunlight, both logs and the forest floor were excellent seed beds. In full sunlight both were unsatisfactory seed beds. But if well established in the shade, some hemlock seedlings survived logging operations and went on to form the nucleus of a new stand.

Hemlock regeneration can be favored by maintaining a dense to moderate overstory and organic rather than mineral soil seed beds. A moderately dense overstory and mineral soil seed bed encourage spruce along with the hemlock. A light overstory or no overstory and mineral soil will encourage the addition of Douglas-fir and red alder where a seed source is present. A common objective is to prevent encroachment of red alder on conifer sites, so maintaining a moderatel[y] dense overstory and minimizing mineral soil seed beds will help. Opening the stand too much can increase risk of blowdown. Exact overstory densities cannot be specified, but local observation of alder encroachment should be helpful in making this decision. Alder will become established on mineral soil seed beds under denser shade than on organic seed beds.

Control of species composition also may be accomplished by contro[l]ling the seed source. For example, the objective may be to favor hemlock over Sitka spruce regeneration in an area where spruce saplin[gs] would be damaged by the white pine weevil. Under the shelterwood system, spruce can be thinned from the overstory during the seed cut, thereby reducing the seed supply.

Whether to use the shelterwood system in hemlock-spruce depends on several factors. Economic comparisons with clearcutting are not available, but logging costs are higher with shelterwood cuttings because several entries are made into the stand and precautions must be taken to protect first the residual stand and later the establishe[d] seedlings. On the other hand, the shelterwood system has an economic advantage in that the new stand gets started while growth continues o[n] part of the old stand, so there is some overlapping of rotation. In part it avoids the period right after clearcutting when seedlings are too small to fully occupy the site.

Commercial thinning in hemlock-spruce stands in Oregon and Washington encourages establishment of natural regeneration in the understory, so by the end of a rotation a new stand may already be established. Unless there is some reason to destroy this new stand,

the main concern of the land manager will be how tall to let the seedlings grow before removal of the overstory, and how to control the logging operation to leave a desired number and distribution of seedlings. Cost increases may be more than offset by the advantage of early seedling establishment. More research on and experience with shelterwood cutting are needed, but the system appears destined for wider use in hemlock-spruce.

There are special situations where the shelterwood system should be used in preference to clearcutting, even though a seed cut may not be needed to encourage establishment of regeneration in the understory. These include areas where it is essential to maintain a continuous ground cover, either for esthetic purposes or to prevent erosion. The shelterwood system can minimize encroachment of intolerant vegetation, such as red alder and bracken fern. Compared with clearcutting, shelterwood cutting can be used to favor hemlock over spruce regeneration, a particularly appropriate objective where the spruce weevil is a problem.

There are also situations where the shelterwood system should not be used. These include areas infected with dwarf mistletoe. Regeneration will be infected by seed showering down from the overstory; this perpetuates the disease. This system should also be avoided in overmature old-growth stands where trees are large. Yarding the large logs can damage the residual stand; residue accumulations are difficult to treat; residual old-growth trees may suffer from exposure or wind damage; and regeneration is easily damaged during overstory removal.

SELECTION SYSTEM

The selection system is aimed at creation or maintenance of uneven-aged stands. It involves removal of trees singly or in small groups at short intervals, continued indefinitely. Small even-aged groups of seedlings appear in the openings thus created. Regulation of the forest is based on development and maintenance of a range of tree diameters, with many trees in the smaller diameter classes and progressively fewer in the larger diameter classes.

A main advantage of the system is that a high forest cover is maintained on the area. Esthetic appeal is maintained, and there is greater stability of environmental conditions for associated animals and plants. The selection system may be used to discriminate against intolerant species by restricting the size of openings in the forest. Thus, it might be used to limit regeneration of red alder, Douglas-fir, and Sitka spruce.

A disadvantage of the selection system is that frequent entries must be made into the stand to remove individual mature trees or small groups of trees. Frequent entries increase the chance of logging damage to the residual stand. Damage to crowns and stems would be a problem on steep slopes that must be cable-logged. With ground equipment, soil disturbance, compaction, and root damage become problems.

Residual, old-growth trees often die from exposure or wind damage (Isaac 1956). Logging costs would be high because relatively small amounts of timber would be removed at a time. Logging would be more complex than with other systems and would require more skill and supervision to prevent damage.

Converting older, even-aged stands with trees of fairly uniform, large diameters to uneven-aged stands with a progression of diameter classes would be a lengthy process. Conversion of near-climax stands having several age classes would also be difficult because of large log sizes and generally defective timber. The selection system would not be suitable for hemlock stands with dwarf mistletoe infection.

Despite these problems, the selection system merits consideratio Selection cutting may have application in scenic areas where both an esthetically appealing forest cover and commercial timber production are desired. It may also be a valuable tool for maintenance of deer habitat in the northern portion of the type. It may not be suitable for recreation areas where open understory conditions are preferred. The system has not been formally tested in the hemlock-spruce type; it should be.

SEED-TREE SYSTEM

In the seed-tree system, selected trees are left standing to provide seed for regeneration. This differs from the shelterwood system in that so few trees are left that they do not provide appreci able overstory protection for the regenerating stand. Hemlock-spruce may be regenerated by seed trees, but the method is rarely used for several reasons. Overdense regeneration usually occurs without the extra seed provided by seed trees; exposed seed trees often uproo or break off in winter storms; and it is costly to harvest the seed trees at a later date.

From the standpoint of timber production, the seed-tree system has little to recommend it. Leaving seed trees of a particular speci could theoretically increase the proportion of that species in the ne stand or lead to genetic improvement by selecting superior trees. Both of these objectives, however, would be better achieved by planti The cost of later harvesting isolated seed trees, or losing them to wind, could go toward financing more intensive cultural measures.

From the standpoint of wildlife management, the seed-tree system might be integrated with a program of snag management. In situations where snags are desired for nesting or perching sites, selection of seed trees could be based on their suitability for wildlife habitat a well as for seed protection.

CLEARCUTTING SYSTEM

Clearcutting is by far the most common method of timber harvesti in hemlock-spruce stands. It is less costly than other methods becau taking all the trees at one time permits spreading fixed costs over large volumes per acre. It concentrates the logging, roadbuilding, a administrative problems into a smaller portion of the forest (fig. 22 It avoids the need to protect residual trees that must be left on the logging area with other silvicultural systems. Clearcutting reduces the number of entries into a stand, an especially important saving ir Alaska where it is expensive to set up and maintain logging camps. I is the only system that makes large-scale harvest cuttings economical feasible in Alaska today (Harris and Farr 1974). From the cost stand point, it is the obvious choice for hemlock-spruce stands.

Figure 22.--Clearcuts near Sitkoh Lake, Chichagof Island, Alaska.

In general, clearcuts become overstocked and stocking control is esirable. The main exception to this is where competing vegetation vertops the seedlings.

Clearcuts may be planned in a variety of sizes and shapes. In he past, clearcuts were large. This concentrated the logging, making or greater efficiency and lower costs, and regeneration proved to be atisfactory in most cases. The recent trend on National Forest land n Alaska has been to reduce the size to 160 acres (65 ha) or less and esign the shape of the cutting boundary to blend with the landscape. his has been done in response to concern for esthetics and wildlife. n the other hand, in Oregon where clearcuts or patch cuts have been maller, a recent trend has been to increase their size as skyline ogging comes into greater use. This also helps to reduce distribution f alder seed. In mixed stands, cutting units are now often made from idge to ridge.

Reducing the size of clearcuts increases costs because more road ileage is needed to reach a given volume of timber. Smaller clearcuts ave more perimeter per area cut than do larger ones, so risk of wind amage around edges is increased. Also, there is less opportunity to ocate cutting lines in windfirm locations.

Minimum clearcut size is influenced by the cost of road construction nd yarding. The cost of developing a landing and setting up yarding

equipment must be balanced against a considerable volume of logs to reduce the cost per thousand board feet. In Oregon and Washington, about 15 acres (6 ha) often is considered minimum clearcut size from this viewpoint; but logging costs vary widely with the type of equipment used.

Clearcuts may be arranged in a variety of ways. Problems with fire in Douglas-fir forests of Oregon and Washington led to the adoptio of the patch cutting system where each clearcut was surrounded by green timber as a firebreak and seed source. This entailed building roads through uncut areas, thereby extending the road system more rapidly than with continuous clearcutting. Patch cutting was extended westward into hemlock-spruce stands with the same objectives in mind (Ruth and Silen 1950), although here fire danger was less and even large clearcuts regenerated well. Patch cutting in hemlock-spruce stands prevails in most areas today, but with less hesitancy in enlargi the size of a clearcut after the original cutover area has regenerated. Restrictions on size and shape of clearcuts come more from multiple-use objectives than from concern about regeneration.

Clearcutting favors spruce in the regenerating stand. Disturbance associated with clearcutting destroys much advance hemlock regeneratio taking away much of hemlock's initial advantage. A cutting area exposed to full sunlight favors the less tolerant and more seral spruce (Harris 1974, Berntsen 1955). Where Douglas-fir and red alder seed sources are available, clearcutting also favors these species. Site disturbance may be increased further by residue treatments such as broadcast burning and yarding unused material, thereby providing added advantage for seral species.

Clearcutting exposes the site to the sun, raises the temperature, speeds decomposition of raw humus, and thereby improves the productivi of the site. It is the preferred silvicultural system for stands infected with dwarf mistletoe, a problem discussed in detail in a later section.

Usually under the uncut timber stand there is a heavy mantle of humus and litter protecting the soil surface. Harvesting the timber disturbs part of this forest floor material and also adds large quantities of logging residue. Generally the soil is well protected. There are exceptions, such as main skidroads, landing areas, deep gorges, and steep shallow soil over bedrock where it is easy to scrape off the soil and deplete the site. Harvest cuttings can be designed to provide various levels of disturbance to a site. Disturbance must be limited to a level that provides adequate soil protection.

Clearcutting also has some disadvantages. It is less desirable esthetically than other harvesting systems. After clearcutting, several years elapse before the site is again fully utilized for timber production. Competing vegetation thrives in full sunlight and tends to take over the site more quickly than with the shelterwood or selection systems. This can be a serious problem if natural regenerat or planting fails, thereby permitting competing brush and red alder to get a head start. In swampy areas, clearcutting may reduce transpirat enough to cause an undesirable rise in the water table.

Harvesting logs does not seriously deplete the nutrient capital of hemlock-spruce ecosystems. Most of a tree's nutrients are in the

eaves, twigs, and roots, and these are left on the site (Journal of orestry 1952). Nutrients removed in the logs will be lost from the ite whatever the harvesting system, so except for some differences in iming, the loss does not enter into selection of the silvicultural ystem. Studies in other forest types have shown that some nutrients ay be carried away in streamflow and, should erosion occur, some will o with the soil that is lost. But, generally, the total loss of utrients is small relative to the nutrient capital stored in the oil or forest floor material.[5/]

Clearcutting is well adapted to harvest of old-growth stands. ny old-growth trees are defective, often mistletoe infected, and om the standpoint of timber management should be removed; but trying o remove only these trees would be difficult. Heavy equipment would e required and damage to the residual stand almost inevitable. eaving old-growth trees, even if sound, does not provide a good eturn on the capital investment in growing stock because growth is w in proportion to tree volume. From the timber production stand- oint, it is best to clearcut old growth and start over with a vigorous oung stand (Harris 1974).

ONCLUSIONS

Clearcutting is recommended as the basic silvicultural system for emlock-spruce forests where timber production is the primary use. It eads to adequate natural regeneration and is economical; it thus eets two important objectives of timber harvesting. It is appropriate or old-growth stands with large and often defective timber--stands ccupying over 80 percent of the commercial forest in southeast aska. In fact, under projected harvesting schedules, the supply of d growth in Alaska will outlast old growth in all other parts of the ited States. The hemlock-spruce forests of Alaska probably will be e last place where large equipment for logging and milling will be quired. With the long time period involved, it is important to rvest the most decadent stands first and to schedule the more thrifty ands for later harvest. Especially important in Alaska, clearcutting lows more solar radiation to reach the forest floor and thus increases ological decomposition of heavy organic accumulations. It is effec- ve in dwarf mistletoe control. It facilitates residue management d fire protection. Through careful selection of equipment and rding techniques, clearcutting can provide a measure of control over te disturbance and density of regeneration. Size, shape, and arrange- nt of clearcuts can be altered to reduce the visual effect of harvest tting.

Clearcutting permits longer cable yarding distances than would be acticable when yarding through standing timber. This reduces road leage and costs, also soil and stream disturbance associated with ad construction. It leaves spacing of roads too wide, however, for inning by cable during subsequent rotations.

Shelterwood and selection systems offer reasonable alternatives clearcutting and should be used when clearcutting fails to meet

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[5/] The effects of clearcut harvesting on forest soils. A summary of major search. 25 p. Compiled by American Forest Institute, 1619 Massachusetts Ave., W., Washington, D.C. 20036.

management objectives. The manager should identify objectives, evaluate alternatives, and prescribe the silvicultural system that best achieves the objectives. The prescription may be a classical textbook system. More likely, it will be a combination of several systems carefully prescribed to reach specific management goals.

SITE PREPARATION

Preparing the site for establishment of a new stand begins with removal of the mature stand. This provides an increase in available light, heat, and growing space for conifer regeneration and competing vegetation. The logging and yarding operation disturbs the soil, damages or destroys understory vegetation, and leaves behind unmerchantable forest residues. The timber harvesting operation provides opportunity for obtaining desired site preparation at low cost. On the other hand, if improperly done, the site can be damaged.

Depending on the intensity of management and ecological factors, managers may be willing to accept the site preparation as accomplished by timber harvest alone. Or they may expend considerable effort on further preparation of seed beds, treatment of residues, and control of competing vegetation.

An excellent review of site preparation methods for use in Oregon is available (Stewart 1978). In the following pages we will briefly discuss site preparation, noting important differences within the hemlock-spruce type.

RESIDUE MANAGEMENT

After clearcutting, forest residues, the unmerchantable organic material that remains, dominate the environment. Depending on circumstances, forest residues are a fire hazard, an obstruction to intensive management, a suitable seed bed for tree seedlings or an obstruction to their establishment, a source of essential nutrients, and a protective cover preventing soil erosion. Usually they are a combination of these.

Basic objectives of residue management are to protect the soil and its nutrient capital and streamflow and water quality and to provide for establishment of a new forest crop. Economic, esthetic, and recreational objectives must also be considered in choosing the most appropriate residue management alternatives.

For the reader interested in more detail than presented here, a state-of-knowledge review of forest residues management in hemlock-spruce forests has been published (Ruth and Harris 1975). A regional state-of-knowledge review of the various environmental effects of forest residues management for the primary forest types of the Pacific Northwest also is available (Cramer 1974).

Viewed just after logging, forest residues are the leftovers--standing dead trees, fallen trees, cull live trees, trees too small to harvest, tree tops, bark, branches, leaves, cones, and stumps.

The long term as well as immediate effects of residues should be valuated in management decisions. Treatment alternatives must be arefully considered, and the best course of action determined. In ome situations, no treatment at all may be the best course. This ill be increasingly true as residue volumes continue to be reduced by mproving utilization standards.

Forest residues are a physical obstruction to intensive management f the new stand. Cull logs, stumps, and piles of debris get in the ay of workers and equipment during thinning and other cultural operaions; some large residues persist until the next harvest cut. Obstrucions make stand treatments more costly and may cause them to be eferred or rejected. The potential yield of the site, therefore, may ot be fully realized. This problem is most acute after logging of efective old growth or stands with a high proportion of cedar (fig. 23).

Figure 23.--Logging slash remaining after clearcut logging of an old-growth hemlock-spruce stand with a high proportion of western redcedar. Cedar shake bolts have been salvaged. Olympic Peninsula, Washington.

Volume and Arrangement

Factors leading to high residue accumulation in hemlock-spruce cosystems include high basic productivity of the species (Briegleb 140; Fujimori 1971; Dimock 1958a, 1958b), infrequent wildfire, a reponderance of old-growth stands, and the cool climate and high

rainfall resulting in more humus and accumulation of organic debris on the forest floor (Gregory 1960). Productivity is more important southward, and lack of wildfire, old-growth stands, and slower decomposition rates are more important in the cooler northern parts of the range.

The volume and arrangement of residues vary, depending on the age and size of the timber stand that was harvested, its volume per acre, defect, structure, and species. Topography, logging method, utilization standards, contract requirements, market conditions, and the logger's skill also contribute. In Alaska and British Columbia where logs are rafted to the utilization plant, small logs and chunks may be left in the woods because they will escape from rafts and be lost.

Residue volume generally increases with stand age and successional development (Howard 1973). Vigorous, young stands contribute few cull logs that in old-growth stands add so much to residue (fig. 24). In the southern parts of the hemlock-spruce type, most stands that are harvested are young. Demand for logs is high, and economic conditions permit better utilization than farther north.

Figure 24.--Slash remaining after clearcut logging of 125-year-old hemlock-spruce with little defect--broadcast burning not planned. Oregon coast, 1973.

Timber volumes are lower in Alaska because of lower site quality; but stands being logged tend to be older and therefore more defective than in Oregon and Washington, so that total volume remaining as residue may equal that in the Pacific Northwest.

In Alaska, stands favored for harvest cutting have been the better, overmature, even-aged stands containing a high percentage of spruce. As logging shifts to more uneven-aged, near-climax stands, residue volume may increase (fig. 25). Offsetting this, as the value of wood increases, less will be left in the woods.

Figure 25.--Residue after harvesting of a near-climax hemlock-spruce stand, Thomas Bay, Alaska, 1972.

Utilization standards in hemlock-spruce forests have generally mproved over the years. Early day loggers seldom took top logs less han 30 in (76 cm) in diameter. Today 6 in (15 cm) is common, and a -in (10-cm) top is the rule on some ownerships. Also, more defective ood is being taken. Currently, there is a market in Oregon for tility logs with chippable content of 50 percent of the gross scale. ontributing to this downward trend in logging residue in Oregon and ashington is the increasing proportion of the annual cut in young tands with little defect, and periodic thinnings which remove defective rees and reduce levels of growing stock.

The arrangement of forest residues is influenced by the logging ethod. High-lead yarding leaves numerous, narrow skid roads radiating rom the landing like the spokes of a wheel; disturbance increases oward the landing. Slash tends to be dragged into the landing with he logs, producing a deep pile. Skid roads are narrow, have slash eft in depressions, and do not form adequate firelines.

Tractor yarding divides residues into sections bounded by skid oads which are often quite adequate as firelines. This facilitates ontrol of wildfire but requires extra effort in setting fire for a rescribed broadcast burn.

Grapple yarding in which at least one end of the logs is lifted ree of the ground disturbs residue less and leaves a more uniform

distribution than high-lead or tractor yarding. Skyline yarding in which logs are soon lifted free of the ground causes still less distu bance, leaving a quite uniform slash distribution (Ruth 1967b). Balloon yarding and helicopter yarding which essentially lift the log directly upward cause the least disturbance.

In Oregon and Washington, red alder stands present a special residue management problem. The most common management objective is to convert alder forest to hemlock-fir, usually by clearcutting and planting. At rotation age, alder stands have much less biomass than conifer stands (Worthington et al. 1960), and residue volumes are correspondingly less. But alder characteristically has a rich understory of shrubs and herbs (Franklin and Pechanec 1968) which becomes part of the residue. The resulting tangle of logging slash and brush obstructs travel and interferes with planting operations. The brush overtops and suppresses conifer seedlings.

Treating Residues

The most common method of handling hemlock-spruce logging residu is to leave them untreated; that is, to utilize as much material as possible and leave the remainder to decay where it falls. This is least costly in current expense, but it may cost more in the long ru For example, in areas of appreciable fire danger, failure to treat residues can contribute to serious losses from wildfire.

Broadcast Burning

Broadcast burning has been the most common method of residue treatment in the southern portion of the hemlock-spruce range. Burn is less expensive than mechanical treatments and does not require heavy equipment that may expose and compact the soil. Use of fire i diminishing, however; and in recent years, pressures have been mount for its elimination because of adverse effects of smoke. On the oth hand, large residue accumulations increase risk of wildfire with uncontrolled smoke production. Controlled burning is still a treatm alternative that warrants careful consideration by forest managers.

The most obvious effect of residue disposal by broadcast burnin is a sharp reduction in fire hazard. Many clearcut areas in Oregon and Washington have been burned for this purpose. Most needles, twigs, and material up to 3 in (8 cm) in diameter are consumed in a prescribed burn, but most larger material is consumed only in part (fig. 26) (Martin and Brackebusch 1974).

Without residue treatment, fire hazard in hemlock-spruce areas decreases gradually as needles drop off, fine materials decay or become compacted by winter snow, and growth of forest regeneration, brush, or hardwoods provides shade that keeps the litter moist.

In case of wildfire, unburned logging residues may offer so man obstacles that building a fireline in the face of spreading fire is impracticable. In this situation, a common procedure is to drop bac to an area that offers less resistance--a truck or tractor road, stream, preestablished fireline, or an area of recently treated resi

Figure 26.--Broadcast burning consumed almost all residue material up to about 3 in (8 cm) in diameter, leaving only the remains of larger logs as a continuing fire hazard, Siuslaw National Forest, Oregon. Divisions on stake indicate 1 ft (30 cm).

Strong arguments for burning develop when there are large accumu-ations of residues, high fire danger, and the likelihood of poor egeneration. This is most common in the southern portion of the ange. Strong arguments against burning develop where fire danger is ow. The obvious example is Alaska where harvested areas rarely dry ut enough to burn. In Oregon and Washington, advocates of non urning often are managing healthy young stands in areas where economic onditions facilitate good utilization. They may be able to exclude he public during periods of high fire danger. They often plan to tilize advance regeneration present on harvested areas.

In general, the trend away from broadcast burning is likely to ontinue. Unlike Douglas-fir and pine, hemlock and spruce have not een dependent on fire for their perpetuation, and fire or similar isturbance need not be an integral part of their ecology. Fire hould not be eliminated but should be retained as a management lternative and used when the benefits outweigh the detriments. urning should be accomplished when smoke will flow away from sensi-ve areas or be carried far aloft by strong convection currents. ocal smoke management plans should be followed. A fast, hot fire ollowed by prompt mopup is desirable.

Prescribed fire can become wildfire. The risk is low in coastal orests, particularly where the residue area is surrounded by green mber, but it does happen and the risk must be evaluated when reatment of residue is considered. Where fire danger is high, the reater risk may be to leave forest residues untreated.

In addition to reducing fire hazard, broadcast burning is useful r reducing the volume of residue that interferes with establishment seedlings and intensive management of the new stand. It can also used to help control competition from unwanted plants. Effects on il will be discussed in a later section.

rding Unmerchantable Material

Yarding of unmerchantable material (YUM) is a contract requirement some public timber sales in Oregon and Washington. The requirement

is that, in addition to removing merchantable logs, all other woody material above specified dimensions, regardless of defect, be yarded to the landing. The dimensions usually specified are 8 in (20 cm) or larger on the large end and 10 ft (3 m) or more in length, but these may be adjusted to any size. YUM leads to improved utilization because once material is at the landing, more may profitably be hauled to a utilization plant. Thus YUM may be used not only to improve utilization but to control the amount and size of residues left on a harvested area. Ecological effects are similar to yarding additional merchantable logs. There is added damage to advanced regeneration, more exposure of mineral soil, reduced fire hazard, and more removal of nutrient capital. The area is opened for planting, and physical obstructions to thinning and other cultural treatments to the next crop are reduced.

Even though some of the defective material becomes merchantable after yarding to the landing and is removed from the site, huge piles of unusable material remain (fig. 27). If the residues are left

Figure 27.--A pile of hemlock-spruce forest residues yarded to the landing.

unburned, the area covered is taken out of production; if they are burned, the underlying soil may receive a "hard burn" according to the definition of Morris (1970). This is of limited consequence because the areas burned are small. Good survival and growth of planted seedlings have been noted on some of these burned areas. Burning is usually delayed until late in the season when surrounding residues are wet from fall rains and air pollution is less of a problem.

YUM has not been required in Alaska or British Columbia, partly because small material tends to be lost from log rafts. It does offer an opportunity to control the volume of residues in an environment where treatment by burning often is not a viable alternative.

YUM yarding is expensive, reportedly sometimes over $400 per acre ($1,000 per ha) in 1974 (Dowdle 1974). A positive benefit cost ratio seems most likely where large volumes of cedar are present.

Other Residue Treatments

Next to broadcast burning, the most common treatment is to burn only heavy slash concentrations--at the landing, where the timber was particularly defective, or where residue has accumulated in depressions (figs. 28 and 29). Burning usually is accomplished during the first fall rains when spread of fire is unlikely.

Figure 28.--Photo taken before spot burning of residue concentrations, Oregon coast.

Piling of logging residues on clearcuts is sometimes done by tractor in Oregon and Washington, usually on areas of high public use or extreme fire hazard. Piled residues usually are burned during periods of moist weather when fire is unlikely to spread. The piles may be left unburned but they then become an obstacle in the way of intensive management of the next timber crop. Piling by tractor would be destructive to most soils in Alaska and is not recommended for use there.

Figure 29.--Photo taken after spot burning of residue concentrations, Oregon coast.

Chipping is becoming increasingly common along roadsides. Unwanted vegetation and limbs trimmed from roadside trees are chipped, and the chips blown into small piles. This improves safety for driver and the esthetic appearance of the roadside.

A layer of chips on the soil surface affects the nutrient status at the site by increasing the surface areas of the residues and thus speeding decay. This tends to tie up nitrogen in decay organisms and may temporarily limit tree growth (Cochran 1968). Not enough chipping has been done to fully evaluate the fire hazard of chips on the soil surface, although chips have been found to be a definite hazard along railroad rights-of-way (Jemisen and Lowden 1974).

Current Practice

Residue management is in transition in the hemlock-spruce type. Improvement in utilization, gradual over the years, has recently been more rapid. Greatest reductions in residue volumes have been near utilization plants where transportation costs are low. Other reductic come from careful felling and bucking to reduce breakage, cutting lower stumps, and utilizing to a smaller top diameter, handling logs more carefully, and using defective logs.

Increased attention is being given to short- and long-term effects of residues on stability and nutrition of soil. Timber harvesting and road construction are planned to keep residues out of streams. If residues fall into streams, they should be removed and placed above high-water level.

In Oregon and Washington, treatment of logging residues differs among forest landowners. Those who have heavy slash accumulations, summer drought conditions above average for the type, or a high proportion of western redcedar slash tend to favor burning. Others require yarding of unmerchantable material, then wait until late fall and burn the large concentrations at the landing. Still others forgo the added yarding cost for the unmerchantable material and burn the heavier concentrations at the landings and on the harvested area. Others leave the slash untreated.

Public land managers often are faced with increased fire risk because of heavy public use, and this tips the scale in favor of burning. Private landowners more often restrict use of their property during periods of extreme fire danger to reduce the risk of wildfire. Some strongly oppose burning of any kind. Often they have a nearby utilization plant and are able to remove smaller material from the area, thereby reducing residue volume.

Broadcast burning in coastal forests in Oregon and Washington may be done in the spring, summer, or autumn, most being done in the autumn during the drying period after rain. Burning in spring is less common than in summer because many areas remain too wet to burn. Some recent increases in spring burning have resulted from smoke management restrictions delaying autumn burning so the treatment is applied the following spring. Smoke management restriction also has provided some emphasis for summer burning which, until recently, was restricted mostly to wet areas with red alder residues.

Firelines are constructed around most slash areas in advance of burning, and water is made available for the more dangerous parts of the perimeter. The organic materials immediately outside the fireline often are wetted down before ignition. The various techniques used for burning are described in detail by Brown and Davis (1973).

Generally in Oregon and Washington, the trend is away from broadcast burning. Major contributing factors are the moist climate, presence of advance regeneration, better utilization, more harvest cuttings in young stands that have little defect, and smoke management restrictions. An increasingly common practice is to not burn at all or to restrict burning to the landing area and heavy slash concentrations. There are, however, heavily decayed, old-growth stands or open stands with dense brush understories where burning still appears to be a necessary treatment.

In British Columbia, residue management on all public and private forest land is prescribed by the British Columbia Forest Service following inspection of harvested areas (British Columbia Lumberman 1971). A guide to broadcast burning of logging slash is available for use where this treatment is prescribed (British Columbia Forest Service 1969). Currently some areas are broadcast burned, some are left unburned, and on some only the residue concentrations are burned. It is the

responsibility of the operator to carry out the prescribed treatment The area must be released by the British Columbia Forest Service before adjacent timber can be logged. The prescription may require special measures to protect the soil, established seedlings, adjacen timber, or other property (British Columbia Lumberman 1969).

Snag falling is required as part of the hazard reduction progra Timber operators may elect to burn additional areas to improve acces for planting or expose more mineral soil seed bed. Part of the roac network is maintained after slash abatement to provide ready access case of wildfire.

Logging operations are closed during critical fire weather. Imp ments have been made in weather forecasts, training, and equipment f fighting fire (British Columbia Lumberman 1969). These changes and increasing public pressure against smoke in the atmosphere have resu in a trend away from residue management by burning. The consensus o Canadian Forest Industries in 1971 was that about 30 percent of slas areas should be burned, although at that time the British Columbia Forest Service was requiring about 50 percent (British Columbia Lumb man 1971).

In coastal Alaska, most commercial forest land is still adminis by the USDA Forest Service or the State of Alaska; the remainder is in small private ownerships. Logging residues on all forest lands essentially are left untreated.

Fire danger is usually low because of the cool, moist climate; and experience since pulp logging began in 1953 has shown the risk o wildfire in slash is not great enough to require treatment to reduc the hazard. Present Forest Service regulations limit the size of most clearcuts to 160 acres (65 ha). This disperses the slash haza and reduces the probability of large fires.

Operators are required to maintain fire equipment on logging operations at all times and during occasional brief summer dry peri may be required to alter working hours or suspend operations.

Snag falling is required on National Forest lands where safety is a factor. Examples are where a falling snag could reach a road surface, rock pit, guyline, or equipment or where snags could inter with helicopter yarding or fire control. All other snags are left for use by wildlife. This policy will doubtless be revised as more information is gained on the use and need of snags by various speci of birds and mammals.

Most of the timber being logged in coastal Alaska is overmatur and defect is often high, resulting in large accumulations of resid Public concern is mainly about esthetics and the apparent waste of raw material. Forest managers are also concerned about the obstruc to future management of young stands caused by large residues. Utilization standards are continuing to improve, and more defective material is being used for pulp. There may be some limited need fo burning in the future, but the present trend toward better utilizat and no burning appears likely to continue.

CONTROL OF COMPETING VEGETATION

Competition from unwanted vegetation can seriously impede regeneration of conifers in the hemlock-spruce type. Understory vegetation is present under mature stands, especially the more open stands; and seral plants proliferate when the overstory is removed.

The problem is most acute in Oregon, where growing conditions are ideal and site productivity is high (fig. 30). The long growing season and relatively warm summers may result in complete cover of brush and tall annuals the year after logging. Unless this vegetation is controlled, adequate regeneration will be much delayed. The problem is acute on moist flats and on slopes, especially where the stand harvested was relatively open or intermixed with alder. Important plant competitors include red alder, salmonberry, thimbleberry, vine maple, evergreen huckleberry, and salal.

Figure 30.--Sitka spruce seedling suppressed beneath dense salmonberry and thimbleberry. Cascade Head Experimental Forest, Oregon.

In British Columbia and Alaska, competing vegetation is most serious on alluvial flats, valley bottoms, and some moist slopes. Here, treatment to control salmonberry, thimbleberry and perhaps other species may be necessary.

Red alder becomes established readily after exposure of mineral soil and is an important competitor of conifers throughout the hemlock-spruce type. Although alder is an important tree species, it is considered an undesirable competitor of conifers in most situations. Red alder is a serious competitor primarily on alluvial streamside soils lacking a thick duff layer, and on upland sites where roadbuilding

or heavy disturbance of the surface organic layer has occurred duri logging. The pattern of roadbuilding and logging is often apparent from the pattern of invading red alder (fig. 31).

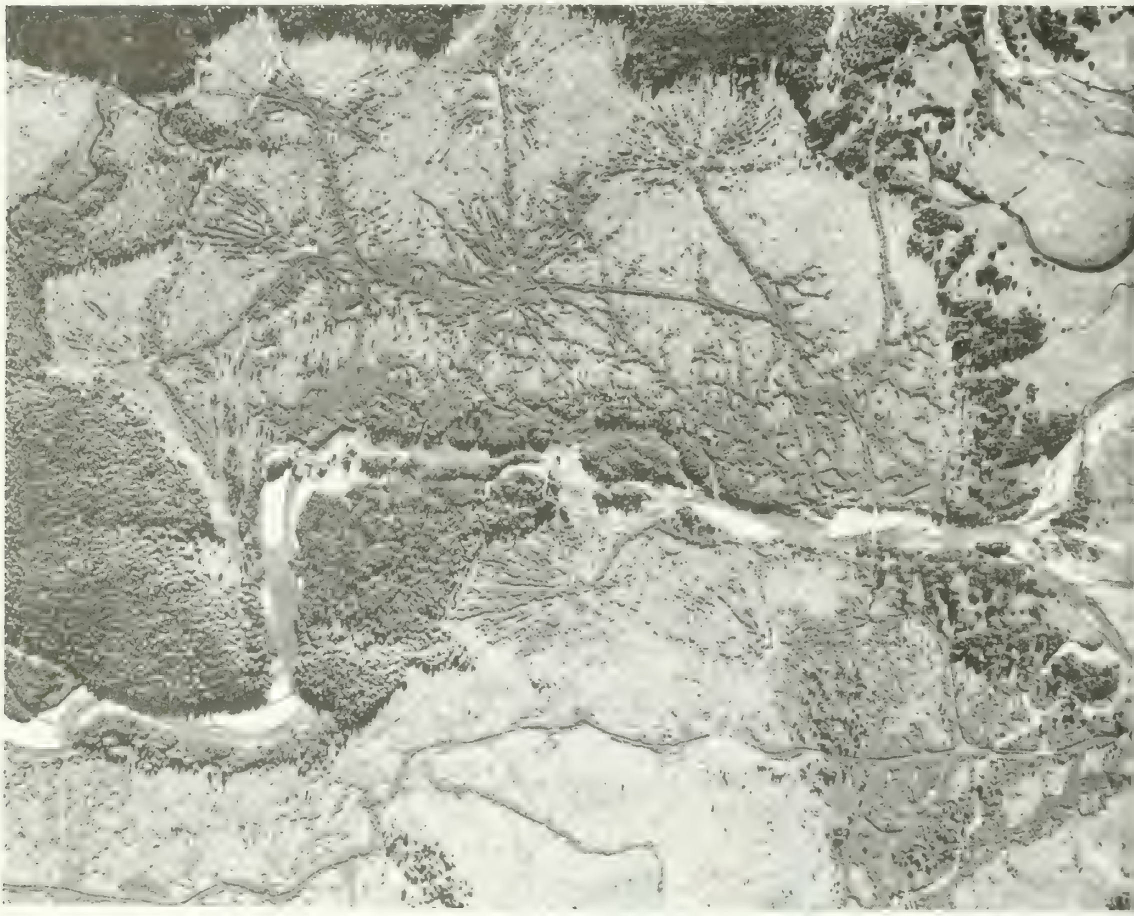

Figure 31.--Alder invasion often follows excessive soil disturbance. The pat of logging is apparent from alder establishment seen in this aerial view 10 years after clearcutting (Katlian Bay, Alaska).

Control of competing vegetation is attempted during two period in the early development of stands: first, for site preparation during or immediately after timber harvest and before conifer regen tion has been established; second, to release conifers if they have been overtopped by faster growing vegetation. Strategies for contr of competing vegetation differ in these two situations. In the fir period there are no conifer seedlings to be protected; in the secon damage to conifers must be avoided.

Two basic approaches to brush control are to destroy brush pla or at least retard their growth and to speed establishment and growth of tree seedlings. Areas threatened by brush should be iden fied in advance of logging, brush control plans developed, and the logging operation designed to facilitate control work. For example, yarding may be arranged to drag logs through brush patches, thus destroying much of the aerial portions of the plants. Treetops may be felled into the brush and burned. These treatments tend to kill

brush plants back to ground level and clear the area for planting. After logging, additional mechanical, burning, and herbicide treatments may be needed.

Mechanical

Mechanical scarification with tractors and tractor-drawn equipment may be useful in some situations in the hemlock-spruce type, although the method has serious limitations. Tractors cannot operate safely on steep slopes, and soil disturbance can lead to erosion and mass-wasting.

Care must be taken to avoid soil erosion and stream siltation that can damage fish habitat. Although scarification may retard or destroy existing brush plants, it may create ideal conditions for invasion by red alder. On youthful soils in Alaska, scalping of the surface organic layer may slow subsequent growth rate of conifers.

Prescribed Burning

Broadcast burning can be used in site preparation to reduce vegetative competition for light, water, and nutrients. In Oregon and Washington, burning may be prescribed almost solely for vegetative control, with reduction in logging residues only an incidental result. Many old-growth stands have low volumes per acre, heavy underbrush, and only scattered regeneration in the understory. Clearcutting without burning perpetuates the brush, which in turn prevents establishment of new seedlings. In Oregon, broadcast burning may be used successfully to control salal and evergreen huckleberry in site preparation. Although resprouting occurs, these plants may be set back enough to allow planted conifers to gain dominance.

Herbicides

Herbicides are used in regeneration work in Oregon and Washington either to prepare sites for reforestation or to release existing seedlings from competing vegetation. It is not necessary to kill all competing vegetation, only to set it back to where it offers less competition to conifers (Gratkowski 1975). More complete control of competitive vegetation is needed for site preparation than for release of existing seedlings.

Herbicides are often used in conjunction with broadcast burning. In the past, some clearcut areas in Oregon and Washington were left untreated and regenerated with a mixture of species. Almost always this included red alder, a few hemlock and spruce, and perhaps other conifers, plus lots of brush, both under the alder and in thickets. Many such areas are now being rehabilitated by an alder conversion operation (Dimock et al. 1976a). A common approach is high-lead logging to remove merchantable logs and to knock down brush and unmerchantable alder; broadcast burning, prompt planting, and herbicide spraying as needed. A brown and burn technique is often used. Herbicide is applied to kill leaves and thereby desiccate green vegetation. A treated area must be burned within a few weeks before vegetation greens up again (Hurley and Taylor 1974).

Use of herbicides is undergoing careful evaluation, and changes in regulations regarding their use are commonplace. Rather than mention specific chemicals and application rates, we will refer to current literature and caution the reader to read this and subsequent literature that becomes available. The advice of competent specialist should be sought and the latest regulations consulted before herbicide are applied.

Considerable information is available on application and effectiv of herbicides on salmonberry, red alder, and other species the land manager may wish to control on hemlock-spruce sites (Krygier and Ruth 1961; Gratkowski 1971; Stewart 1974a, 1974b). The season of application is important (Gratkowski 1971). So is the formulation of the herbicide (Gratkowski 1975). For example, the iso-octyl ester of 2,4-D ((2,4-dichlorophenoxy) acetic acid) has been found to cause far less mortality to salmonids than the butyl or PGBE (propylene glycol butyl ether) esters (Meehan et al. 1974). Several summary publications contain information particularly applicable to hemlock-sp sites (Gratkowski 1967, 1975; Stewart 1978).

The shelterwood system of harvest cutting offers a means of accomplishing alder control and favoring hemlock. Theoretically, enough overstory may be left to shade out alder, then the overstory removed after hemlock is well established. This system, however, has been little used because of economics and because in Oregon and Washington many land managers want at least some Douglas-fir in the regenerating stand.

In Alaska, primary competition is from red alder and salmonberry (Harris 1967). Almost no herbicides have been applied, but new regulations for National Forests require immediate regeneration of all cutover land and are prompting a reevaluation of regeneration practic. Site preparation, including control of unwanted vegetation along with immediate planting, appears necessary to meet management objectives on affected sites.

Most problem sites are adjacent to salmon spawning and rearing streams and tributaries where fishery values are high. Consequently, great care must be taken to assure that site preparation will not damage fish habitat. Any future use of chemicals will require carefu evaluation to assure that there is no reduction in water quality or damage to aquatic organisms.

REGENERATION

The regeneration method for a particular area should be selected not as an individual item but in connection with a silvicultural system that makes the best compromise between management objectives, environmental factors, and costs. The land manager must select the basic harvest cutting system and plan the residue management, the site preparation, and the seeding, planting, and control of competiti that may be needed.

Regeneration planning, often stratified by entire clearcut units, should be more detailed and provide for varying treatments within units. Thus, a particular clearcut may be partly overstocked

with advance regeneration that needs thinning, have an area needing residue treatment to expose suitable microsites for planting, and have brush patches where control of competition and planting of large seedlings are needed. In the regeneration prescription the manager should specify the species, type, age, size, and condition of planting stock and should carefully match the seedlings to the variable site conditions in the field. Plans should be made in advance of harvest cutting to allow time for producing the planting stock but should be kept flexible to meet changing field conditions.

SEED

Genetics and Selection

Compared with knowledge of other conifers, little is known about genetic variation in western hemlock and Sitka spruce. Variations in Sitka spruce have been described by Burley (1966), Daubenmire (1968), Pollard et al. (1975). Information on the genetics of Sitka spruce has recently been reviewed (Roche and Fowler 1975; Harris, in press). Provenance research in western hemlock is underway by the British Forestry Commission (Piesch 1974), and existing information indicates that the species is well suited to genetic improvement efforts (Piesch 1974, 1976).

For natural regeneration, seed from adjacent stands or occasionally from residual trees are depended on to regenerate clearcut areas. This is generally accepted practice with most species, including hemlock and spruce. With artificial regeneration, the land manager should be sure the seed source is genetically adapted to the area being regenerated; this is best done by selecting seed of local origin.

Within a local seed source, individual trees vary genetically in growth rate, timber quality, and other characteristics that affect tree value. Substantial genetic gains may be made by using seed from trees having desirable characteristics. Always there is a risk that selected trees are lacking in less obvious characteristics, such as drought resistance, frost hardiness, and insect or disease resistance. Selection on the basis of specific characteristics has the potential for reducing the genetic base of the regenerated forest. With our present limited knowledge, replacing the original gene pool with an "improved" strain could turn out many years later to have been a costly mistake. In deciding on a genetic tree improvement program, the forest manager would be well advised to take a cautious approach that will maintain genetic diversity (Silen 1976).

Seed Collection

Most western hemlock and Sitka spruce cones are picked from standing or recently felled forest trees or collected from squirrel caches. Many cones can be obtained from trees recently cut by felling crews, but there is limited opportunity to collect from the best trees.

When local seed are not available, care must be taken that seed from a suitable source are used. As a broad guide, seed collection zones have been established within the hemlock-spruce type in Oregon

and Washington (Western Forest Tree Seed Council 1973) and in British Columbia (Dobbs et al. 1976); zones are being developed for Alaska.

When possible, it is desirable to select superior trees or stands, reserve them from cutting, and collect cones from them repeat as needed and as cone crops occur. This approach involves climbing or otherwise gaining access to the crowns of tall trees. Collection techniques using ladders, hydraulic platforms, climbing gear, and tree nets are described by (Eversole (1954), Seal et al. (1955), and Hutt (1957).

Cones should be collected during late September and early October. The cutoff point is when seed fall begins, usually the latter part of October (Ruth and Berntsen 1955, Harris 1969). The earliest date for collection varies by species. Harris (1969) studie the 1966 seed crop near Juneau, Alaska, and found that spruce seed ripened about 3 weeks earlier than hemlock, reaching maximum viabilit by September 3. Hemlock viability was still low on September 3 but increased rapidly the week of September 10, then continued to increas slowly through the final collection on October 16. As spruce cones ripen, their color changes from light yellow green to yellow red (Safford 1974). As hemlock cones ripen, their color changes from green with purple tips to brown with red-brown tips (Harris 1969).

Hemlock and spruce cones awaiting seed extraction are usually stored in loosely filled permeable sacks in opensided cone drying sheds. Ample air circulation is needed around each sack to minimize heating and buildup of mold. Green cones should be surface dried before storage. An excellent guide to collecting cones of important conifers in the hemlock-spruce type is available (Dobbs et al. 1976).

Seed Extraction

Seed extraction procedures for hemlock and spruce cones follow those for most conifers--air drying or kiln drying to open cone scales and tumbling to extract the seed. Kiln temperatures usually are set at 90° to 110°F (32° to 43°C); drying time is 2 to 48 hours, depending on moisture content of the cones.

Extracted seed are cleaned by screening out cone scales, dirt, and debris; dewinging; and fanning to remove wings, hollow seeds, and dust.

Seeds of most trees within the hemlock-spruce type are small (Schopmeyer 1974) (table 4). They are light and easily damaged and must be processed carefully.

Seed Storage

Several years can elapse between bumper seed crops, so annual planting and seeding programs depend on successful storage of seed. Seed of both hemlock and Sitka spruce keep best below the freezing point; generally seed are stored at 0°F (-18°C). Barton (1954) showed that viability was maintained better at this temperature than at 12°F (-11°C) or 25°F (-4°C); distinct differences showed up after

Table 4--Cleaned seeds per pound of common tree species within the hemlock-spruce type[1]

Species	Number of seeds per pound (kg)	
	Average	Range
Western hemlock	260,000 (573 000)	189,000-508,000 (417 000)-(1 120 000)
Sitka spruce	210,000 (463 000)	155,000-400,000 (342 000)-(882 000)
Douglas-fir	39,000 (86 000)	29,000-46,000 (64 000)-(101 000)
Western redcedar	414,000 (913 000)	203,000-593,000 (448 000)-(1 308 000)
Red alder	666,000 (1 468 000)	383,000-1,087,000 (844 000)-(2 397 000)

[1] Schopmeyer (1974).

years of storage. Maintenance of viability can be expected for at east 5 years, and this generally bridges the gap between large seed rops. Lavender (1956) demonstrated that temperatures and humidities xperienced between removal of hemlock seeds from storage and testing r seeding do not appreciably reduce viability.

Pregermination Treatments

Stratification of western hemlock seed increases rate of germination ut has only minor effect on total germination (Bientjes 1954, Ching 1958, uszewicz and Holmes 1961, Edwards 1973). Seed stratified for 3 weeks t 33°F (1°C) germinated faster than untreated seeds. Longer stratifi- ation periods caused additional but smaller increases in rate. tratified seed also germinate more uniformly. For example, germination ates between unstratified seed lots varied by 8.6 days in the time o reach 50-percent germination, whereas seed lots stratified for weeks varied by only 3.6 days (Edwards 1973). Fast germination educes the length of a critical survival period for the seedling. niform germination also simplifies nursery operation and reduces ariation in seedling size. Seeds usually are stratified by presoaking least 24 hours at room temperature, then are drained and placed in cold room at 34° to 41°F (1° to 5°C).

Seed Testing

Official rules for testing viability are to place seed on a otter or in a petri dish. For hemlock, temperature should be intained at 68°F (20°C) for 28 days and the seed exposed to at

least an 8-hour photoperiod. Recent research, however, has shown that maximum germination rate and value occur with a 4-hour photoperi An 8-hour photoperiod resulted in a slower germination rate, about the same as in total darkness, but 16- to 24-hour photoperiods significantly depressed germination rates (Edwards and Olsen 1973).

For spruce, the rules call for alternating temperatures of 68°F and 86°F (20°C and 30°C) for 21 days. A photoperiod should be suppli and more than 8 hours may benefit some seed lots. Stratification prior to testing is not required for either hemlock or spruce (Association of Official Seed Analysts 1970).

NATURAL REGENERATION

Seed Production and Dissemination

Western hemlock and Sitka spruce seed production generally is adequate for establishment of regeneration even on large clearcuts, so few areas fail to regenerate from lack of seed (Harris 1967, Ruth and Berntsen 1955). Failures more often are due to competing vegetation and can be aggravated by occasional seed crop failures that give the competition a head start on tree seedlings.

Natural regeneration after clearcutting is influenced by directi of seed dissemination. Hemlock and spruce cones tend to open and seed to disseminate during periods of dry weather (Harris 1969). After cones mature in the autumn, cone scales open and close in response to dry and wet atmospheric conditions with much flexing of cone scales during the season. Dry winds along the coast normally blow from the north and east, causing cones to open and seed to disseminate south to west. Winds suddenly switch direction as low pressure areas approach. Toward the south this shift is to the southwest, in Alaska to the southeast. There is a lag period before cone scales are closed in response to the higher humidity, so some seed are disseminated northerly. These may be storm winds that carr seed considerable distances. One season was noted in coastal Oregon when no dry periods occurred after October seed maturation. This eliminated that burst of seed fall expected with the first northeast wind. Seed fall stretched over a long period, and dissemination was northeasterly. Usually, dry winds do occur and a seed source locate on the northerly side of a clearcut probably is more effective than one on another side.

Rate of fall of hemlock seed is 2.6 ft (8 m) per second and spruce 3.1 ft (0.9 m). This compares with 4.4 ft (1.3 m) for Dougl 4.95 ft (1.5 m) for Pacific silver fir, and 5.1 ft (1.6 m) for weste redcedar (Siggins 1933), so hemlock and spruce seed should reach farther out into clearcut areas than these associates.

Seeding Establishment

Western hemlock and Sitka spruce seed will germinate and seedl will grow on a variety of seed beds. It is the adverse factors of the environment that limit seedling establishment. These include drought, frost heaving, surface heat, flooding, animal damage, and

competition from neighboring plants. We will discuss "mineral soil" and "organic" seed beds.

Organic seed beds are generally considered to be the surface organic layers; the litter, fermentation, and humus layers, including rotten wood. Mineral soils are generally considered to be the A2, B, and C horizons. Soil material, when mixed and not in the context of horizons, is arbitrarily considered to be organic soil if it contains at least 12-20 percent organic carbon, depending on clay content (USDA Soil Conservation Service 1975). Soil containing less organic carbon than this is mineral soil.

In Alaska hemlock and spruce will germinate on both organic and mineral soil seed beds. Establishment and subsequent growth, however, is much better on soils with a high percentage of organic material. Nitrogen and mineral nutrient element content are far higher than in mineral horizons below (Heilman and Gass 1974). Mineral soils stripped of surface organic material may be unsuitable seed beds because underlying soil horizons contain few nutrients to support growth. It does not follow, however, that logging should always minimize surface disturbance. Logging practices usually do not remove surface horizons over large contiguous areas. Disturbance tends to be patchy. Mineral soil horizons are exposed when moving logs scrape furrows. Stumps are uprooted when logs hang up and tear them out, exposing mineral soil. Logs tend to slide over residue accumulations without disturbance to underlying ground surface but gouge or scrape the surface briefly when they pass beyond. Ground surface is often irregular; moving logs tend to gouge protruding hummocks but pass over low spots. Thus, productive surface horizons may be removed, piled deeper, or mixed with lower horizons.

Shade affects suitability of seed beds. Minore (1972) found that both duff-covered soil and rotten wood were good seed beds under shade but neither were suitable under full sunlight. Preserving duff accumulation under shaded conditions benefited growth of all conifer species tested.

Suitability of organic seed beds versus mineral soil seed beds varies with latitude, exposure, and the extent of the seed bed. In Alaska, most seed beds are organic and that is where most seedlings become established, both in light to moderate shade or in the open. Mineral soil seed beds may be suitable if their extent is limited, but nutrition soon becomes a problem. Southward in Oregon and Washington, exposed organic matter is more likely to dry out in the sun so that a seedling's radicle is killed before it can penetrate to available moisture. Sometimes the radicle will make initial penetration during wet weather, only to have a dry spell cause organic material to dry downward so fast that the radicle cannot keep up with receding moisture. A few sunny days during the germination period can cause heavy seedling mortality (Ruth 1967a). On the other hand, soils are better developed than in Alaska and nutrients are available in lower soil horizons to support good tree growth.

On exposed organic seed beds, lethal surface temperatures may kill the seedlings. The surface of a dry seed bed exposed to full sun may reach temperatures above 150°F (66°C), depending on moisture, exposure time, and sun angle. Organic material, being a poor conductor, cannot conduct heat downward as well as a mineral soil can. It

becomes hotter and more seedlings are killed than on mineral soil seed beds. Toward the south, exposed organic seed beds become less and less hospitable for seedling establishment, until few seedlings establish on organic seed beds on clearcuts.

Type of seed bed also affects species composition. Douglas-fir and red alder prefer mineral soil seed beds, so increasing the organ content of seed beds favors hemlock and spruce over the more seral species.

Where moisture or temperature are limiting, shade improves seedling establishment. Even a small object shading the lower quart inch (6 mm) of a seedling stem may prevent lethal seed bed surface temperatures. Thus, a rough soil surface is more favorable for seedlings than a smooth one. Herbs and shrubs reduce surface temper tures. Live vegetation uses soil moisture, but generally this does not overcome beneficial effects of shade. The surface layer that is so important for initial seedling establishment retains more moistur in the shade than in the open.

On the other hand, shade can be dense enough to prevent seedlin establishment; for example, dense, young hemlock-spruce stands at th sapling stage are almost devoid of understory vegetation, including tree seedlings. Salmonberry and thimbleberry thickets also provide heavy shade in the summer, and autumn leaf fall smothers most seedli that survive the shade.

Organic seed beds that remain cool and moist enough for seedlir establishment have the advantage that few plants other than hemlock and spruce will grow on them. Thus, the tree seedlings have little competition for moisture and nutrients. When only occasional seedli are found in brush areas, almost invariably they are growing on rotten wood.

The excellent regeneration obtained on Oregon clearcuts genera occurs when the microsite is shaded in some way--by logging slash, vegetation, or perhaps by no more than an irregularity in the surfa that shades individual seeds during germination. Seedlings also ma get started during a wet spring that gives them time for root growt to keep up with receding moisture levels when dry weather arrives. Less shade is needed to the north because dry periods are less comm

Hemlock and spruce seedlings often invade openings dominated b other vegetation by becoming established on logs that have fallen into the opening from an adjacent timber stand (Davidson 1967).

Western hemlock and Sitka spruce seed remain viable on the forest floor over winter and germinate the following spring. Seed failing to germinate does not hold over to future years (Isaac 1940

The effectiveness of natural seed fall or artificially sown se can be increased by poisoning rodents on the area to be regenerated. Hemlock and spruce usually are prolific enough that this is unneces Many poisons have been banned because of the undesirability of introducing them into the food chain.

Effects of Forest Residues on Seedling Establishment

Harvest cuttings and the resulting residue accumulation should eave an environment suitable for establishing a new timber stand. resh logging residues are unsatisfactory seed beds (fig. 32); but fter decay is well advanced, the radicle from a germinating seed can enetrate the surface and the decaying wood provides adequate nutrition or seedling survival and growth (Morris 1958, 1970). Litter that overs the surface further improves the seed bed and may speed decay f the underlying wood. In contrast to hemlock and spruce, Douglas-fir nd red alder seldom become established on rotten wood.

Figure 32.--Five years after logging and seeding, this seed bed of logging residue remained nonstocked. Note residual hemlock seedlings nearby. Maybeso Experimental Forest, Alaska.

Logging residues intercept natural seed fall or aerially sown ed. They cover mineral soil seed beds, obstruct the movement of anting crews, and make impractical the maintenance of a specified acing of planted trees. Slash accumulations contribute to the umped tree distribution often apparent in young hemlock-spruce ands. Slash-caused openings tend to seed in eventually but the lay retards stand development, causing variation in height and age the new stand. On the other hand, partial shade provided by derate amounts of logging slash improved early survival of spruce d hemlock on mineral soil during an abnormally dry summer in Alaska arris 1967).

Forest residues affect tree seedlings in several incidental ways. Bark may slough off a log or stump and cover nearby seedlings. Some seedlings become established under logs or large limbs, only to have the leader grow up into these logs or limbs and be damaged or grow around them, causing a deformity. Sometimes residues settle to the ground and crush seedlings. Other seedlings are damaged as their leaders sway in the wind and rub against residues. Residues tend to creep downslope under the weight of a heavy snowpack and destroy small seedlings in their path.

Residues also limit access to tree seedlings by cattle and big game, thereby reducing browsing damage. On the other hand, they provide shelter for the small mammals that damage seedlings.

Where frost damage is a problem, forest residues intercept outgoing long-wave radiation and tend to slow nighttime cooling. They also slow cold air drainage. The net effect is variable.

In Alaska, Harris and Farr (1974) noted that on alluvial streamside sites subject to flooding, Sitka spruce and western hemlock seedlings become established alongside stumps or atop decayed logs or debris and thus avoid the intermittent high water.

The foregoing relationships between hemlock-spruce forest residues and tree seedlings can be used to influence seedling establishment. The major concerns are to speed seedling establishment, improve spacing, and control species composition. Residue management affects all of these.

Mechanical removal of residue will increase disturbance of the area and expose more mineral soil. In the southern hemlock-spruce range additional exposure may be obtained by broadcast burning.

Control of Advance Regeneration

When hemlock and spruce seedlings are in the understory prior to harvest cutting, the overstory removal cut can provide some stocking control. Overstocking can be reduced by yarding systems, such as high-lead, that cause considerable ground disturbance. Conversely, needed regeneration can be protected by skyline yarding systems that lift logs free of the ground.

A high level of disturbance destroys most advance regeneration and delays seedling establishment until new seedlings germinate or are planted. Logging disturbance also is useful when a different species or genetically superior stock is to be planted. Usually advance regeneration is hemlock, and disturbance facilitates establishing a mixture of spruce or Douglas-fir by natural regeneration, seeding, or planting. Toward the south mineral soil deliberately may be exposed to provide seed beds or planting sites. Anywhere in the type, disturbance will increase the chance for alder invasion if a seed source is present.

Broadcast burning destroys most advance regeneration and, unless the area is planted or seeded, delays seedling establishment until after the next seed crop. This may be several years, and burned areas are routinely planted to avoid risking this delay.

Since burning destroys most advance regeneration, burned areas initially have fewer seedlings than unburned areas do, and seedlings may be better distributed (Harris 1966). But where burning exposes additional seed beds, the potential for subsequent regeneration may be greater than without burning (Berntsen 1955, Gockerell 1966, Hetherington 1965).

Harris (1966) found spruce seedling establishment was better and hemlock poorer on a burned compared with an unburned area, indicating that burning might be used to increase the proportion of spruce. This is consistent with Sitka spruce's role as a more seral tree species than western hemlock.

A decision to save advance regeneration insures that logging residues will be intermixed with the tree seedlings and compounds the difficulties of treating residues. Trials of the shelterwood system in southern hemlock-spruce forests emphasize the difficulties. Clearcutting with protection of advance regeneration produces all the logging residue at one time. On the other hand, a seed cut and one or more removal cuts create residues over a span of several years, with time for some decay to take place between cuts. A decision of whether or not to treat residues should be made prior to each cut.

PLANTING

More western hemlock and Sitka spruce are being planted. Complacent feelings about hemlock-spruce regeneration are changing to a sense of urgency. Supplies of old growth are exhausted on many private ownerships in Oregon and Washington, and survival of utilization plants now depends on rapid establishment and growth of young stands. The National Forest Management Act of 1976 (U.S. Laws, Statutes, etc. 1976) requires rapid restocking of cutover National Forest lands. With a short rotation, a 5-year delay in regeneration can mean about 0-percent reduction in wood supply. Greatly increased land and stumpage values make it costly to expand land ownership or purchase logs on the open market. It is important then that each acre designated for timber production be promptly and adequately stocked with desirable trees. Gains in timber production through tree improvement programs are possible, and this requires planting superior seedlings and the ability to propagate them.

In Alaska, there is far less emphasis on planting and seeding than in Washington and Oregon and natural regeneration is the primary means of restocking cutover land; however changes are coming. Problem situations have been defined, container planting stock is being produced and planted, and pilot attempts have been made to control competing vegetation.

A common goal is to have every acre successfully regenerated within 1 year of clearcutting. The planting of highly productive sites to speed stand establishment and shorten the rotation has become standard practice on some ownerships. Planting is often used to improve species composition. Control of competing vegetation usually is an important part of the regeneration process.

Production of Planting Stock

Production of western hemlock and Sitka spruce planting stock is currently undergoing rapid change as containerized seedlings are used as well as the traditional bare-root seedlings. Growing seedlings in containers under controlled conditions is an advantage for these small-seeded species because germination and initial estab ment have been a problem in outdoor nursery beds. The demand for bare-root hemlock seedlings generally has exceeded the supply, so fo some landowners the several nurseries now producing containerized hemlock seedlings provide their first opportunity for planting this species without resorting to wild seedlings found in the forest.

Information is available on production of bare-root seedlings i forest nurseries (Aldhous 1972, van den Driessche 1969, Armson and Sadreika 1974).

Western hemlock and Sitka spruce seedlings are difficult to gro in outdoor nursery beds. Their small size makes them particularly susceptible to frost heaving in cold weather and to heat damage in warm weather. Seed beds may need screening to protect seeds from birds and rodents. Nursery production has been low compared with ot Pacific Northwest species, and nursery practices are not fully worke out (Ruth 1974, Long and Winjum 1974).

A recent approach is to grow bare-root seedlings in nursery bed-houses. Seeds can be sown as early as February and large transp seedlings produced in 2 years (Cowles 1976). Production of rooted cuttings is also being investigated (Boyd 1976). Research with containerized seedlings is providing basic information applicable as well to production of bare-root stock (Stein 1974).

Container-grown seedlings are being used at an increasing rate in reforestation in the West (Stein and Owston 1977). In recent years, the technology of producing seedlings in containers has under- gone rapid development; and the technology used today for production of container-grown seedlings has been well described (Sjoberg and Matthews 1977, Tanaka and Triebwasser 1976, Tinus et al. 1974, Stei and Owston 1977, Cleary et al. 1978). Facilities range from simple shade frames to elaborate greenhouses (fig. 33). Some facilities ar equipped with supplemental lighting. Within these, seedlings are grown in a variety of plastic containers (Tinus et al. 1974).

Figure 33.--The technology of containerized seedling production is undergoing rapid change. Western hemlock and Sitka spruce seedlings are being grown in this experimental greenhouse located at Beaver Creek, Oregon.

A container system provides opportunities to manipulate the nvironment and regulate development of seedlings. For example, ud set may be induced by reducing water, withholding nitrogen, and hortening the photoperiod. Growth can be extended into the fall by rolonging the photoperiod (Cleary et al. 1978).

Potential advantages of using container-grown stock over bare-root tock include: faster production and more flexible growing schedules, educed root disturbance and less planting shock, extended planting easons, easier planting on adverse sites, and higher quality of emlock and spruce seedlings.

Potential disadvantages include: higher costs of production and ransportation, generally smaller seedlings, and tendency for abnormal oot growth and frost heaving.

In Alaska propagation of seedlings is still in the experimental tage; emphasis is on container production in greenhouses. Container roduction appears to be more feasible than bare-root production in irseries because of the cool summer temperatures, high rainfall, hort growing season, and the lack of suitable nursery sites. Growing eedlings from Alaska seed sources at established facilities in States arther south does not appear feasible now. In addition to high ransportation costs, there are problems with seedling growth. Trees rom high latitudes become dormant under the shorter photoperiod and rowth cannot be maintained[6/] (fig. 34). Hemlock and spruce seedlings

Figure 34.--Four-month-old Sitka spruce seedlings, Juneau, Alaska, provenance: Right, grown under normal day length for latitude of provenance (58°18'N.); left, grown under day length for latitude 48°50'N.

6/ Personal communication from Richard W. Tinus, Principal Plant Physiologist, U DA Forest Service Shelterbelt Laboratory, Bottineau, N.D.

from Alaska sources cannot be grown successfully at lower latitudes unless the photoperiod is extended, and most available nurseries do not control photoperiod.

Handling, Storage, and Transportation

The time between removal from the nursery or greenhouse and planting is critical for seedlings. For bare-root stock, this period is probably more critical than for container stock, as roots are more exposed to environmental stress. Extremes of heat, cold, and drought are especially damaging.

Hemlock and spruce seedlings require careful handling to insure good survival. Care should be taken that roots are not exposed to drying conditions and seedlings are protected from extremes of temperatures. Seedlings should be dormant during storage, handling, shipping and planting. An excellent source of more detailed information and references has been provided by Cleary et al. (1978). In general, environmental stress caused by warm, dry conditions is more important toward the south. Costs and logistics of truck, boat, and air transportation are of more concern toward the north.

Planting Guidelines

Much of the information available for other forest types is applicable to hemlock-spruce. An excellent overview of current practi used in Oregon has been provided by Greaves and Hermann (1978).

Hand planting is required in virtually all situations throughout the type. Hillsides usually are too steep for machine planting, and flat bottom land is too wet. Also, in most areas where old-growth stands are logged, heavy logging residues create obstacles to machine planting whether or not broadcast burning is done.

Several field experiments comparing container and bare-root planting stock have been established. In Oregon and Washington, early results indicated no significant difference in survival rates between the two kinds of planting stock (Gutzwiler and Winjum 1974). In contrast, Arnott's (1976) results from low-, medium-, and high-elevation hemlock plantations in British Columbia showed that containe grown seedlings survived better than bare-root seedlings, but growth rates were about the same.

For any planting stock, successful survival in the field depends heavily on a seedling's ability to withstand moisture stress. Bigger and better seedlings will help, whether containerized or bare root; but seedling quality seldom makes up for poor preparation of the site. Generally, it is better to apply such measures as treating logging residues and reducing competing vegetation than to try to solve proble by selection of planting stock. Both site preparation and the best planting stock are usually needed to achieve successful regeneration of problem areas. In addition, where animal damage is a problem, special measures may be necessary to protect seedlings (see page 107).

)IRECT SEEDING

With natural hemlock and spruce seed fall generally adequate, lirect seeding has been confined to special situations. These include seeding to supplement a poor seed crop or replace a seed crop failure, :o increase the proportion of a particular species in the new stand, :o regenerate inaccessible areas where planting costs would be excessive, ind to reforest large burns or other areas left without a natural seed source. Direct seeding is not a satisfactory method of combating regeneration failures caused by competing vegetation. Early growth of seedlings is slow and they are readily overtopped.

Direct seeding trials have met with some success but with frequent ailure (Shaw 1953, Harris 1965). An important problem was seed osses to rodents. Losses can be greatly reduced through use of odent control chemicals, either on the seed itself or by baiting the rea prior to seeding (Carmichael and Dick 1956); but restrictions on se of poisons have largely eliminated this practice. It should be ossible to improve seedling establishment by reviving the old technique f sowing an excess of seed. For example, Isaac (1939) found that a atisfactory stand of Sitka spruce could be established by broadcast eeding at the rate of 1 or 2 lb/acre (1.1-2.2 kg/ha) of seed if seeding as done within 2 years after a slash burn. This approach seems ppropriate in areas with low rodent populations or where planting is mpractical. But, in general, the inability to use rodent control hemicals, high cost of seeds, and development of new nursery and lanting techniques have tipped the scales in favor of planting as the est artificial regeneration method.

THINNING

Thinning is the systematic regulation of growing stock in a young orest (Malmberg 1965). Trees are removed in young stands to stimulate rowth of the remaining trees and to increase financial return. This s accomplished by removing and utilizing trees that otherwise would e crowded out of the stand and lost, and by concentrating growth on ewer, larger, and physiologically more efficient trees. Thinnings ay also be made to control species composition, improve windfirmness, ncrease forage, or for esthetics, recreation, or other purposes. ollowing a thinning, the openings made in the canopy should be closed y growth of the remaining trees. Objectives of a thinning should be early defined and silvicultural prescriptions written accordingly. he emphasis in this section is on management of young stands for ncreased financial return.

Young hemlock-spruce stands vary in stocking, but understocking s rare. Most, having originated from prolific natural seed fall, are erstocked. Trees that reach harvestable size, having undergone tense competition, are smaller than had they been released from mpetition by early thinnings.

Thinnings may be characterized in several ways. Under *stocking ontrol*, also called precommercial thinning or spacing, most of the cut ees are left on the site, and the operation requires a financial investnt by the landowner or manager. *Commercial thinning* pays its own way rough sale of trees taken from the stand. *Thinning intensity* refers the volume of trees removed from the stand. It may be expressed as

a percent of the total stand volume. Often it is expressed as an annual thinning yield--the volume removed in a thinning divided by the number of years since the last thinning. Expressed this way, thinning yields may be compared between stands regardless of the length of the thinning cycle.

Type of thinning refers to the dominance class or quality of trees removed from the stand. A *low thinning* removes trees predominantly from the lower canopy; a *crown thinning* takes trees from the upper canopy. A *selection thinning* removes dominant trees to stimulate growth in lower crown classes. In a *mechanical thinning* trees are taken predominantly on the basis of a predetermined spacing. A *free or combination thinning* is a combination of methods (Smith 1962). For additional terminology pertaining to thinning, see Ford-Robertson (1971).

Thinning decisions are based on both silvicultural and economic considerations. Silviculturally, thinning should provide improved growing conditions for crop trees. Economically, thinning should increase the financial return to the forest owner.

BIOLOGICAL FACTORS

Both hemlock and spruce respond well to release, particularly after stocking control and early commercial thinning. Thinning a stand removes part of the growing stock and results in reduced growth per acre immediately afterward because the remaining trees are not able to fully utilize the site. The reduction in growth is roughly proportional to the reduction in growing stock. Released trees build up root systems and crowns and are soon better able to exploit the resources of the site. Initial response probably comes from the availability of nutrients no longer being utilized by trees that were removed. Root systems may expand more rapidly than crowns because roots do not have to support themselves structurally (Smith 1962). Trees with large crowns will expand their photosynthetic area more rapidly than those with small crowns. There is evidence (Moller et al. 1954, Braathe 1957, Bradley 1963) that a stand not only recovers its normal rate of growth but also tends to make up the production lost when growth was below normal immediately after thinning. With heavy thinnings and long recovery periods, however, nutrients may be taken up by competing vegetation or leached from the site. In general there is good recovery in wood production following heavy thinnings in the early part of the rotation. Heavy thinnings near the end of the rotation tend to reduce volume production.

The upper canopy not only intercepts a significant portion of total radiation but selectively filters out the most photosynthetically active wavelengths from the light that gets through (Assmann 1970). It follows that overtopped trees are not efficient producers of wood. They could be left, utilizing available light not used by the overstory. This would increase total wood productivity unless the moisture and nutrients required for growth were used by trees in the overstory.

An immediate effect of thinning is an increase in risk of wind damage. This risk is greatest after heavy thinning in stands nearing rotation age. Trees are tall, root systems may be poorly developed, and mutual support is an important factor in stand stability. As a

rule of thumb, removal of over one-third of stand basal area is not recommended. Thinning of young stands is less risky. Trees are short, respond quickly to release, eventually developing better roots and greater windfirmness than before thinning.

If dwarf mistletoe is present in a hemlock stand, thinning may stimulate growth of the parasite by increasing available light. Growth rate of host trees may be reduced even though trees are not killed. The problem is discussed in more detail later.

For any thinning operation, particularly when thinnings are removed from the site, care must be taken to protect the residual stand. Roots of hemlock and spruce are shallow and bark is thin. Hemlock is especially susceptible to decay because it is not protected by resin production to the same extent that Sitka spruce and Douglas-fir are. Damage to roots and stems provides entry courts for disease organisms (Wright and Isaac 1956, Worthington 1961, Hunt and Krueger 1962, Wallis and Morrison 1975).

Fomes annosus root rot may be a serious problem in thinned stands of hemlock. Infection of crop trees can occur from root contact with infected stumps left from the previous stand, from logging wounds on crop trees, or from root contact with stumps infected after thinning[7/] (Driver and Wood 1968, Wallis and Reynolds 1970). The number of stumps infected may be greatest soon after thinning, declining over a 5-year period (Morrison and Johnson 1978. Treatment of stumps immediately after cutting can help to prevent infection (Edmonds et al. 1969, Weir 1969, Russell et al. 1973). Borax has been used for this purpose in the past, but zinc chloride appears to have advantages in wet weather (Morrison 1977, Morrison and Johnson 1975).

EFFECTS OF THINNING ON TREES AND STANDS

Thinning determines the size distribution of the trees; for example, thinning from below eliminates smaller trees and immediately increases the average diameter and height of a stand. Thinning distributes the growth potential to fewer and larger stems. It tends to reduce log quality because branches, particularly in the lower crown, persist longer, grow larger, and produce larger knots. The added sunlight encourages epicormic branching in Sitka spruce.

Optimum thinning intensity usually is the maximum volume that can be removed from the stand without seriously reducing volume production. With heavier thinning, spacing may be so wide that the site is not fully utilized for timber production. Wide annual rings and large knots will lower wood quality. With lighter thinning, spacing may be so close that trees are suppressed. Rings will be narrow and knots small, but logs will be too small for efficient handling. The canopy should be deep enough for efficient use of light; but if tree crowns are too long, little clear wood is produced. Forty percent live crown is considered optimum for western hemlock (Walkup 1975). A common rule-of-thumb is to remove no more than 30 percent of the basal area at the time of the first commercial thinning.

[7/] Edmonds, R. L. 1968. Natural occurrence and control of *Fomes annosus* in precommercially thinned stands of western hemlock. M.S. thesis. Univ. Wash. 144 p.

Thinning affects species composition. Thinning from below removes mostly hemlock and thereby tends to increase the percentage of spruce crop trees. On drier sites where the whitepine weevil is a problem, thinning tends to favor hemlock by removing damaged spruce. Where Douglas-fir is present, thinning from below generally favors fir over both hemlock and spruce.

THINNING AS A STIMULANT TO UNDERSTORY VEGETATION

Thinning may stimulate establishment and growth of understory vegetation by increasing the amount of sunlight reaching the forest floor. This is beneficial if understory plants are desired for wildlife. It is detrimental if understory plants seriously compete with the timber stand for moisture and nutrients or, at a later date, with conifer regeneration. On the other hand, understory vegetation may help retain nutrients that otherwise might be leached out of the ecosystem. Thinning may speed decomposition by adding a mixture of broadleaf litter to the conifer litter from the timber stand (Smith 1962).

Thinning may also stimulate establishment of conifers, primarily hemlock, in the understory (Farr and Harris 1971). If thinning is done near rotation age, this could speed establishment of the next crop, as with the shelterwood system. Early thinning may result in a two-storied stand which will require attention during subsequent thinnings. The response of understory vegetation to various thinning regimes is now under study in Alaska.

ECONOMIC FACTORS

Financial evaluation of thinning requires careful formulation of management objectives. Common objectives are to increase stand yield--thereby, in many situations, justifying an increase in the present allowable cut; maximize profits with a limited capital investment; or perhaps improve the stand for wildlife or recreation use. Merits of several criteria for economic evaluation of management practices are discussed by Haley (1969) and Webster (1965).

The end products of the final crop need to be identified. Usually they are pulp logs, saw logs, or a combination. At present there may be little demand for thinnings, particularly where old growth is available and the added costs of thinning are not offset by lower stumpage costs; for example, in Alaska, British Columbia, and portions of Washington. Elsewhere, integrated utilization plants accept most log sizes and grades. Whatever the end products, their values, along with operating costs, can be estimated and discounted back to the present, with and without thinning. Doing this on an individual stand basis is often inadequate, because treatment of one stand will affect the management of other stands, and what is best for the timberlands division of a company may not be best for the company as a whole (Schweitzer 1972). An exception to this dollars-and-cents approach is on public land where timber production may not be the dominant use.

Thinnings can increase the financial return from the forest in several ways. Foremost is by utilization of trees that in an unthinned

nd would die and decay before the end of the rotation. In Douglas-fir, example, Worthington and Staebler (1961) show mortality losses to 33 percent, depending on age at first thinning, site class, lization standard, and method of measuring volume. Mortality ses also are high in hemlock-spruce. Much of this loss can be icipated and prevented by recognizing trees likely to drop out of stand and removing them in periodic thinnings.

Commercial thinning provides an early return on the capital ested in growing stock, thereby freeing funds for other activities. slow-growing trees usually are removed, leaving a more vigorous nd that provides a better rate of return on the investment.

Thinning affects rotation length by concentrating growth on fewer es. The time to reach a given diameter is shortened. Transfer of wth to fewer trees occurs more rapidly in fast-growing young stands n in slower growing stands approaching rotation age. Some of the t effective thinnings are those made before the trees can be utilized thus require an investment by the landowner.

Later thinnings necessarily must take some of the better trees. r rotation age, when trees are larger, removal of a single tree ves so large an opening in the canopy that it takes considerable e for adjacent trees to fill it and again fully utilize available light.

Type of thinning affects capital investment in growing stock. any given thinning intensity, removing more valuable trees in a wn thinning is more effective in reducing the capital invested than vesting small trees in a low thinning. On the other hand, slow-growing rmediate and suppressed trees have a low percentage of growth. Their oval provides economic return with little loss in stand growth. n respond to release. Some may need only a little diameter growth ecome recruits into a merchantable size class, their entire volume g added to the stand at that time. Thinning from above can be y, however, as intermediate and suppressed trees are generally not firm, and removal of larger, faster growing trees carries the risk etaining genetically inferior trees.

Tree size is an important factor in the cost of thinning. In a g stand it takes longer and costs more per unit volume to fell l trees than large ones. As stands grow older and trees larger, s differences because of size disappear, and felling cost is directly oortional to tree volume (Crowther 1964). Yarding and loading also s more for small logs. These factors favor wide initial spacings, t this must be balanced against heavier branching that would result d the loss of increment from delayed closing of the canopy.

Volume per acre also affects thinning cost. The higher the lme harvested in one operation, the less time it takes to gather gther a load of logs and the lower the cost of supervision.

Economically, thinnings should increase the financial return from rest. Remote and low-site land may not justify thinning at all, erhaps a single stocking control treatment early in the life of e stand will be all that is appropriate. The situation may be versed, however, when thinning on poor sites is needed to bring es into merchantable size classes.

THINNING STRATEGY

Thinnings should be governed by some reasonably definite schedule, indicating the desired density of the stand at all stages of its development. This is necessary not only for thinning control but also for predicting yields that will be obtained (Smith 1962). Thinning schedules are not fully developed for hemlock-spruce; but research, general theory, and field experience provide some guidelines.

The British approach has been to identify the productivity of the site in terms of maximum mean annual increment (Bradley et al. 1966, Hoyer 1967, Hamilton and Christie 1971). The height and age relationship is used to indicate this, much as we refer to height-over-age curves to determine site index. The British adopted a common objective for all species, thinning to an intensity that provides the greatest mean diameter increment for the main crop, consistent with maximum production of volume. This removes volume to the point that would affect total productivity. It was concluded that removing 70 percent of the maximum mean annual increment would meet this objective. The thinning cycle may be one to several years, but not so often that crop trees cannot respond enough to make full use of the growing space. The volume to remove in a particular thinning is obtained by multiplying 70 percent of the maximum mean annual increment by the thinning cycle (Bradley et al. 1966).

This method of controlling the volume of thinnings removed rather than controlling remaining growing stock has three advantages:

1. It provides consistent production from thinnings, which facilitates planning and makes for efficient harvesting.

2. It reduces the effect of an error in determining productivity class, since thinning volume is much less than growing stock volume.

3. It avoids a drastic reduction in growing stock if the stand is overstocked, which might lead to wind damage (Bradley 1971).

The lightest thinning to avoid volume loss would remove merchantable trees just before they drop out of the stand or salvage them before they decay. Light thinning causes growth to be distributed among more but smaller trees than with heavy thinning. Crowns and limbs will be smaller, thus improving wood quality.

There is little danger of thinning hemlock-spruce so lightly that stagnation occurs. Even in strictly even-aged stands there is usually adequate differentiation into crown classes. This is especially true with mixed hemlock-spruce stands because spruce usually assumes a dominant position in the canopy.

Competition begins early in hemlock-spruce stands, often when seedlings are less than a foot tall. Thinning at this stage is impractical with present techniques; and when seedlings are subjected to a short period of intense competition, weaklings drop out early in the rotation. Subsequent thinnings allow a choice from among the best trees of what was a considerably larger population, so there is little risk of depleting the gene pool.

Biologically, stocking should be controlled just before crowns of potential crop trees become constricted enough to materially slow diameter growth. But there are some practical considerations. It is difficult to move about in dense young stands, especially when there is a major component of Sitka spruce with its stiffer branches and sharp needles. This argues for delaying stocking control until low limbs die and begin to fall off. Also, hemlock-spruce stands often have small seedlings in the understory, seedlings too small to cut with a powersaw. If released, they respond vigorously and a two-storied stand results. It is common practice, therefore, to delay stocking control until tree crowns have been closed long enough to shade out most of these seedlings and associated understory plants. On the other hand, delaying the first thinning too long delays the release of crop trees and may leave stems of the crop trees exposed to sunscald or may contribute to snowbreakage or wind damage. Heavy thinnings are more risky than light ones. Exposing intermediate and suppressed trees is more risky than exposing trees in the upper canopy which have had more opportunity to build up windfirmness.

STOCKING CONTROL

Stocking control usually is prescribed in terms of tree spacing or stems per acre (fig. 35). All but the selected trees are cut or killed and left standing. Uniform spacing is usually compromised to leave the largest and most vigorous trees. Uniform spacing also may be sacrificed to improve species composition. Sometimes a tree will get so far ahead of its neighbors it is destined to have large limbs, poor log quality, and take up too much space. Such trees may also be removed in stocking control.

Figure 35.--This dense, 19-year-old hemlock-spruce stand at Maybeso Valley, Alaska, was thinned, leaving crop trees spaced 16 by 16 ft (4.9 by 4.9 m). About 6,300 trees per acre (15,600 per ha), averaging 1.6 in (4 cm in diameter, were cut.)

Usually stocking control is done only once. The spacing is selected so that by the time tree crowns again are crowded, stems will be large enough for commercial thinning. The spacing to use, therefore, depends on future utilization standards and accessibility. If the stand is close to market, close spacing may be appropriate; if far from market, wider spacing should be used. Wide spacing is appropriate if the stand will be allowed to grow to rotation age without further thinning. This would require spacing so wide that the stand would not fully occupy the site for several years. It would encourage brush establishment in the understory. Additional conifer regeneration would likely become established, perhaps defeating the purpose of the thinning. Common spacings at present are 9 by 9 to 12 by 12 feet or 538 to 302 trees per acre (2.7 by 2.7 to 3.7 by 3.7m or 1,329 to 746 trees per ha) in anticipation of at least one commercial thinning later in the rotation.

Average stand density increases with latitude (Meyer 1937, Barnes 1962). Stands in Alaska have more stems per acre but lower average diameter and less volume than in the Pacific Northwest. The reason probably is that site productivity decreases with latitude (Farr and Harris 1979). Also, seedling survival may be greater in the cool, wet northern climate (Harris and Farr 1974).

Timing of the first thinning depends on many practical considerations not the least of which is the landowner's policy on silvicultural investments and the owner's ability to finance a thinning, the benefits of which will not accrue for several years. Most owners of large areas of industrial forest land and the public agencies in Oregon, Washington and British Columbia have aggressive stocking control programs in hemlock-spruce stands. For the most part, owners of small areas are managing their land less intensively.

COMMERCIAL THINNING

The first commercial thinning may be conducted as soon as the trees are crowded enough to need thinning and the operation will at least break even economically. This may be early in the rotation if stocking control has concentrated growth on fewer stems, later if it is the first thinning. Timing also depends on the accessibility to market and the market for small logs. Subsequent thinnings can be made as tree crowns expand and fill in the gaps in the canopy. High sites should be thinned more often than low sites and young stands more often than old stands.

LOW THINNING

Low thinning forestalls natural mortality that occurs as trees become overtopped and crowded out of the stand. Removal of suppressed trees relieves competition for moisture and nutrients but does little to relieve competition for sunlight. Because openings in the main canopy are avoided, low thinnings retain the mutual protection trees provide each other against storm damage. On the other hand, upper canopy trees are not stimulated to build up added windfirmness. Should a break occur in the canopy, continuing wind damage may follow.

Thinning from below tends toward an orchardlike condition in the nain canopy, in which sunlight penetrating the canopy is not used for vood production because there are no tree crowns below to utilize it. ?articularly with very tolerant trees like hemlock, it seems advisable to maintain a deep forest canopy for full utilization of sunlight.

Low thinning requires a minimum of marking skill because it removes trees whose crowns have dropped below the main canopy. Crown thinning is more flexible and requires more marking skill.

ROWN THINNING

Crown thinning removes codominant and dominant trees from the nain canopy to favor more promising trees in these same crown classes.)ominants may be favored as the most vigorous and windfirm crop trees)ut sometimes are removed because of large limbs that degrade log juality. Codominants usually have better quality but tend to be smaller and less windfirm. In a strict crown thinning, no intermediate ind suppressed trees are harvested, and their presence tends to restrict levelopment of understory vegetation. Opening up the main canopy ermits better light penetration and slows mortality of lower branches. itka spruce may be stimulated to develop epicormic branches. Crown hinning may stimulate understory trees to grow into a merchantable iameter class. The added light may encourage growth of understory egetation, thereby improving forage for deer.

In the Scottish eclectic method of thinning used in some Sitka pruce plantations in Britain, the main crop trees are identified and he major thinning objective then becomes uninterrupted development of he effective crowns on these trees. A deep canopy is maintained by eaving smaller trees (the followers) surrounding each crop tree. ominant and strong codominant competitors of selected crop trees are emoved as needed, and trees suppressing or otherwise crowding desired ollowers are removed (MacDonald 1963).

ELECTION THINNING

Selection thinning of dominants in hemlock-spruce stands generally s limited to removal of large, poorly formed trees occupying space it of proportion to the wood values produced. These are best removed arly in the life of the stand when trees are more wind resistant and hile nearby subordinate trees have adequate crowns to respond to elease. With tolerant species like hemlock, subordinate trees usually e present to fill spaces left by removal of rough dominants. Heavy repeated thinning of dominants is not suitable for hemlock-spruce ecause of increased probability of wind damage to the residual stand.

MBINATION THINNING

Most hemlock-spruce stands are variable enough that no single tpe of thinning is sufficient. Often there are rough dominants ccupying excessive growing space which should be removed if other tees are available to replace them. Marking policy may favor hemlock, sruce, or perhaps an associated species, justifying departure from

the usual criteria of crown position and tree quality. Thinning to minimize wind damage often is an overriding criterion as will be discussed later.

A logical thinning sequence begins with a precommercial thinning--a combination of mechanical and other types of thinning--followed by one or more crown thinnings but taking trees from the lower canopy as they reach merchantable size. Thus, later thinnings are called low thinnings.

In general, type of thinning has little effect on gross volume production (Bradley 1963). Bradley concluded that for practical purposes thinning may be controlled in intensity, independent of type of thinning, and that changes from one type of thinning to another can be made during the life of a stand without seriously complicating calculation of total volume production.

TREE SELECTION AND HARVEST

Selecting the Individual Tree

The general approach to thinning is to identify the trees most efficient for volume production--those that produce the greatest volume of wood for the space they occupy--and thin to favor them. The success of thinning depends on the subsequent development of these individual trees.

Matthews (1963) generalized for several species, including the spruces, that efficient trees have relatively long, narrow crowns with upper branches angling upward and lower branches more or less horizontal. Trees with large crowns and branches are not necessarily the most efficient producers for the space occupied. Seed production makes considerable demands on carbohydrate resources of a tree at the expense of wood production. Heavy seed producers, unless needed to seed adjacent areas, are best thinned out of the stand. Trees to favor have straight stems without excessive taper; have small limbs; are circular in cross-section; and are free of buttressing, spiral grain, fluting, and forking. Efficient trees usually have a dense mass of healthy foliage. It is particularly important to recognize crop and noncrop trees early in the life of the stand, even though some of their characteristics are difficult to detect at that time.

If a policy is set to favor a particular species, then some compromises in tree quality may be necessary. The desired species may be present but not the best tree from the standpoint of position in the canopy and health.

There are several commonsense guidelines to timber marking which normally apply, whatever the general approach to thinning. Large-crowned dominants taking up excessive growing space should be marked if it appears that their increment will be replaced by release of nearby trees. Mistletoe-infected trees, rotten trees, and poorly formed trees should be cut. All merchantable dead and down material should be designated for removal. Hangups, trees that lodge into others when cut, are a common problem in dense hemlock-spruce stands. The timber marker can help to alleviate this problem by not marking a tree that

nay hang up or by marking it and the tree it would lodge against. Scattered trees far from the landing are costly to harvest. The marker should be familiar with yarding procedures and costs and consider these factors in selecting trees for harvest.

Whatever the intensity and type of thinning prescribed for an area, the timber marker should be allowed discretion in handling special situations. He may encounter wide variations in soil moisture, species composition, stocking, competing vegetation, topography, and age class. Areas subject to storm damage require special treatment. So do areas with more than one age class of trees. Thinning rules may be varied to meet market demands for special products or log sizes. The timber marker should be provided with adequate guidelines and have the training, experience, and authority to handle such situations as they arise in the field.

Equipment and Techniques Used for Stocking Control or Thinning

Both powersaws and chemicals have been used for control of stocking. Saws are the less costly method when there are many small stems to cut, chemicals when there are fewer and larger stems. Schroedel (1971) analyzed costs in western Washington and recommended using powersaws where the average stand diameter is less than 2.5 inches (6 cm) and 2,000 or more stems per acre will be cut. Powersaws also are an advantage over chemicals when the trees to be cut have limbs all the way to the ground. MSMA (monosodium acid methanearsonate) and cacodylic acid have been the chemicals commonly used. These organic arsenicals can be dangerous to the applicator unless adequate precautions are taken (Wagner and Weswig 1974). Some organizations are minimizing chemical use because of the problem of monitoring health of employees. Also, because it is difficult for thinners to distinguish treated trees, thinning standards are difficult to maintain and the crew's job satisfaction suffers (Waterman 1976). Standing dead trees deteriorate more slowly than slash on the ground, and this is also a point against poisoning or girdling. Public concern over use of herbicides is another. For these reasons cutting trees rather than poisoning or girdling them is the preferred method of removing unmerchantable trees today.

With powersaws, the usual technique is to sever the stems and move on. Some trees will fall, but many will be held up by adjacent trees and will be felled later by wind or snow. Initially, thinning leaves an unsightly tangle of dead limbs and stems. This residue can be cleaned up by lopping, piling, burning, or chipping; but this is costly. Cleanup usually is limited to keeping slash off roads and out of streams and roadside ditches. An alternative is to leave unthinned strips along roads and streams. In sensitive areas these strips can be thinned after the residue on the main area has fallen to the ground. Then only a limited amount of residue needs to be treated.

Yarding of Thinnings

Hemlock and spruce trees are easily damaged because of their thin bark and shallow roots, particularly during active growing periods. Special care should be taken to protect them from logging injury.

This is difficult because trees are growing during the summer, often the only time crawler tractors or rubber-tired skidders can operate. During other seasons, these machines may cause soil compaction and root damage or may simply get bogged down in the mud.

The construction of permanent tractor trails and landings in advance of thinning operations can do much to alleviate damage to the stand, protect soil and water resources, and improve safety and harvesting efficiency. Long-term as well as short-term requirements for thinning operations can be met by careful preplanning and construction. The technique is currently being tested in Oregon[7]

Cable yarding often is preferable to use of tracked or wheeled vehicles and is the only practical means on steep slopes. It avoids most root injury and soil compaction. Stem injury, however, may be greater. Special care should be taken in logging layout, choker setting, and yarding. Improved techniques need to be developed.

A study in the nearby Douglas-fir type (Aulerich et al. 1974) showed that log production rates for skyline yarding were greater thai for tractors on steep ground, but less on gentle ground. Overall, skyline yarding cost 1.5 to 1.6 times more than tractor yarding. It left more slash but caused less soil compaction and resulted in fewer serious wounds to residual trees.

PRESENT STATUS OF THINNING

Research and experience in thinning hemlock-spruce are recent, and few long-term results are available. In Oregon and Washington thinning began after World War II in stands 100 to 125 years old. These stands were past rotation age, but there were large acreages in these and older age classes. To meet even-flow objectives harvest cutting time was extended through commercial thinnings. Objectives were to salvage existing mortality, remove defective trees, and remov trees expected to die before the stand was scheduled for final harves cutting. Thinnings were confined to gentle topography where crawler tractors could be used. As demand for timber increased and technolog for handling small logs improved, commercial thinning spread to more ownerships, younger stands, and, with development of cable methods, t steeper slopes. The first commercial thinning in coastal hemlock stands under age 50 years was started in 1947, when a 47-year-old stand of hemlock was thinned (see footnote 7).

Commercial thinning is becoming more common in Oregon and Washin on and spreading northward. Conventional logging methods have not prove satisfactory and economics has been a limiting factor in thinning hemlock (Dick 1976). But there has not been time for long-term tests of thinning, and thinning guides are only in the development stages. Managed-stand yield tables have been prepared for pure Sitka spruce and pure western hemlock plantations in Great Britain (Hamilton and Christie 1971, Bradley et al. 1966), but comparable information for managed stands of hemlock-spruce has not been developed for North America.

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[7] Personal communication from Donald B. Malmberg, Crown Zellerbach Corp., Seaside, Oregon, 1977.

In Alaska, thinning has been limited because of the predominance of old-growth stands, poor accessibility, and limited markets for small material. A test in an even-age stand near rotation age showed that thinning favored growth of crop trees and resulted in prolific regeneration (Godman 1951, Farr and Harris 1971).

Stocking control in precommercial stands of hemlock-spruce is now common practice in Oregon and Washington. In British Columbia a juvenile spacing program began in 1961. By 1977, 105,735 acres (42 823 ha) had been spaced, mostly on the Vancouver Forest District. Most of this has been done on licensed tree farms and certified tree farms (Johnson 1977). In Alaska stocking control is being done on a small scale, along with studies designed to develop managed stand yield tables.

Although detailed silvicultural effects and financial returns cannot be predicted at this time, adoption of intensive thinning programs by forest industry and government agencies illustrates the widespread conviction on the part of forest managers that thinning hemlock-spruce will indeed pay.

FOREST FERTILIZATION

In the Pacific Northwest, interest in forest fertilization began about 1950 when fertilizer trials were begun in immature Douglas-fir stands in western Washington (Gessel et al. 1969). Results were encouraging and by the mid-1960's private timber companies had aerially applied nitrogen in the form of urea over several thousand acres (Clark 1967, Forbes 1966).

Most fertilization in the Pacific Northwest has been of Douglas-fir, but interest has also been shown in western hemlock. By 1975, fertilizer trials had been established on nearly 1,000 hemlock plots (DeBell 1975, DeBell et al. 1975, Webster et al. 1976). The nutrient requirement of hemlock has not been extensively studied (van den Driessche 1976).

In the case of Sitka spruce, little experience has been gained on the Pacific coast although a great deal of work has been done in Great Britain. Extensive studies on the nutrition of Sitka spruce, mainly in nurseries, date back to the 1950's (Benzian 1965). By the mid-1960's many young stands of Sitka spruce had been aerially fertilized in Scotland (Davies 1967, 1969).

In Alaska, the U.S. Forest Service tested large-scale aerial applications of urea in young stands of hemlock-spruce to gain experience in methods, costs, and logistics of large-scale applications in remote areas (Johnson 1970, Bowkett 1969). Between 1969 and 1972, about 5400 acres (2,200 ha) of 6- to 15-year-old hemlock-spruce stands were fertilized by helicopter using urea prills at a rate of 400 lb per acre (448 kg/ha) (Farr et al. 1977).

Growth response of western hemlock from fertilizer application in the hemlock-spruce type has been inconsistent. Response of western hemlock in basal area growth on nearly 1,000 plots in Oregon, Washington, and British Columbia fertilized primarily with urea ranged from -20 to

+47 percent (DeBell 1975). A detailed analysis by Webster et al. (197
showed that response differed by geographic location; response in coastal areas within the hemlock-spruce type was generally slight (oft negative), whereas inland stands responded better. There also appeare to be a tendency for an increase in response with latitude from southe Oregon to northern Vancouver Island. Trees in the upper crown classes showed better response than trees in lower crown classes. No consiste trends emerged regarding response associated with stand age, stand density, site quality, or soil type. Response in thinned stands was generally higher and more consistent than in unthinned stands.

Growth response of Sitka spruce in mixed stands of hemlock-spruce was greater and more consistent than hemlock, based on tests near Seaside, Oregon (Webster et al. 1976). In comparing tree growth associated with fertilization, Farr et al. (1977) found that 2 years after application of urea the growth rate of Sitka spruce was from 20 to 30 percent greater in height and diameter on areas fertilized than on areas not fertilized; by the 5th or 6th year, there was little difference in growth rate. Response of western hemlock could not be measured because hemlock on both fertilized and unfertilized areas were infected by the fungus *Sirococcus strobilinus* (Farr et al. 1977). Later investigations by Wicker et al. (1978) indicated some tendency for fertilizer application to favor the fungus, but results were not conclusive.

The effect of forest fertilization on water quality was also examined in Alaska. Meehan et al. (1975) studied water quality of two streams whose watersheds had received aerial applications of urea. He found that concentrations of nitrate nitrogen in both streams were higher than normal during a 1-year sampling period. An initial short-
increase in ammonia-nitrogen occurred in one stream, apparently from the inadvertent direct application of fertilizer to the stream. In all cases, however, concentration of nitrogen remained well below the upper limits permitted for human consumption.

Fertilization has been proposed as a substitute for precommercial thinning. The rationale for this has been that adding nutrients increases site productivity and tree growth, which in turn hastens natural thinning. Field trials have failed to clearly demonstrate the effectiveness of this approach. Studies indicate that reductions in overstocking as a result of fertilization will be much slower and in most cases less beneficial than from thinning (Miller 1976).

Aerial fertilization is an attractive tool for forest management because large areas may be treated quickly with a minimum of effort. Growth responses on the average, however, have been low, inconsistent, and of relatively short duration. At present, fertilization alone does not appear promising. We still know far too little about the basic nutritional requirements of hemlock and spruce and their respons to fertilizer to be able to predict results. Application of fertilize alone does not now appear to be sound practice in the hemlock-spruce type.

GROWTH AND YIELD

Western hemlock-Sitka spruce is one of the world's most productiv forest types. The high productivity is attributed to the mild, moist

limate during the growing season and to high genetic capability of he species (fig. 36). Pacific Northwest tree species survived leistocene glaciation without serious depletion of the gene pool,

Figure 36.--A mixed stand of western hemlock and Sitka spruce 79 years old. Cascade Head Experimental Forest, Oregon.

because the north-south orientation of the mountain ranges permitted species to migrate south and north as the climate varied and glaciers advanced and receded. In contrast, species in many other parts of the world were cut off by east-west mountain ranges (Silen 1976).

The Pacific Northwest coastal climate is excellent for tree growth. Temperatures are mild during the long growing season and even on clear days do not get high enough to excessively increase respiration rates. Soil moisture is adequate. So, apparently, is solar radiation, in spite of the cloudy weather.

The Olympic area appears optimum for hemlock-spruce. Dimock (1958b) measured growth on three groups of 0.2-acre (0.08-ha) plots in 35- to 60-year-old stands on the Olympic Peninsula, Washington. Hundred-year site index was 160 to 200 feet (49 to 61 m); net periodic annual increment for a 5-year measurement period ranged from 160 to 293 ft^3 per acre (11.2 to 20.5 m^3/ha). Northward, productivity decreases with increasing latitude and decreasing temperature. Through most of the type, 100-year site index decreases about 3.4 ft (1.0 m) per degree of latitude and averages about 156 ft (48 m) in Lincoln County, Oregon, and 108 ft (33 m) in northern southeast Alaska (Farr and Harris 1979).

A 26-year-old western hemlock stand in coastal Oregon believed to be at a peak stage of production had a total biomass of 103 tons per acre (231 metric tons/ha); 65 percent was in the main stem (table 5). This is a huge biomass accumulation in only 26 years, and net accumulation was continuing at a rate of 16.1 tons per acre (36.1 metric tons/ha) per year (Fujimori 1971).

Table 5--Accumulated and annual biomass production of a 26-year-old western hemlock stand on the Oregon coast, dry weight basis

Component	Accumulated biomass		Current net annual production	
	Tons per acre	Metric tons per hectare[1]	Tons per acre	Metric tons per hectare[1]
Stem	67.3	150.9	9.1	20.4
Branch	9.2	20.7	1.9	4.3
Leaf	9.4	21.1	2.7	6.0
Root	17.1	38.4	2.4	5.5
Whole	103.0	231.1	16.1	36.2

[1] From Fujimori (1971).

EARLY HEIGHT GROWTH

Juvenile height growth of hemlock and spruce seedlings varies wi site index, the genetic potential of each seedling, and the micro-environment where the seedling happens to germinate or be planted. Microenvironments vary widely, and their influence often dwarfs other factors for the first few years. A seedling with very rapid growth potential may do poorly the first few years because of competing vegetation or other localized environmental conditions, and juvenile height growth may lead to an underestimation of subsequent growth. I other situations the converse may be true.

Estimates of stand age are often made by aging trees at breast height, 4.5 ft (1.4 m) above the root collar, and estimating the number of years for the seedling to have reached that height. Age at breast height rather than total age is often preferred as a more useful variable for subsequent growth and yield estimates.

The juvenile growth period is an important part of the rotation and any condition that slows growth will increase rotation length or reduce yield. For maximum growth, competing vegetation should be controlled and overcrowding of seedlings avoided or spacing treatment applied. Treatment must be applied early in the life of a stand to b most effective. If delayed too long, much of the opportunity for improving stand growth and yield will be lost.

SEASONAL DISTRIBUTION OF LEADER GROWTH

Seasonal leader growth of both hemlock and spruce starts in lat April or early May, accelerates slowly for 2 to 3 weeks, undergoes a sustained period of rapid elongation, and finally tapers off for several weeks in July and August. Godman and Gregory (1955) took

ekly measurements of leader growth at Hollis near Ketchikan, Alaska, d found that both species began growth about the same time but that ruce grew faster and stopped growth 2 to 6 weeks sooner than hemlock fig. 37). Gregory (1957a) compared seasonal distribution of hemlock eader growth at Hollis, Alaska, with growth at Cowichan Lake on ancouver Island (Buckland 1956) and found time of growth initiation d shape of the growth curves similar.

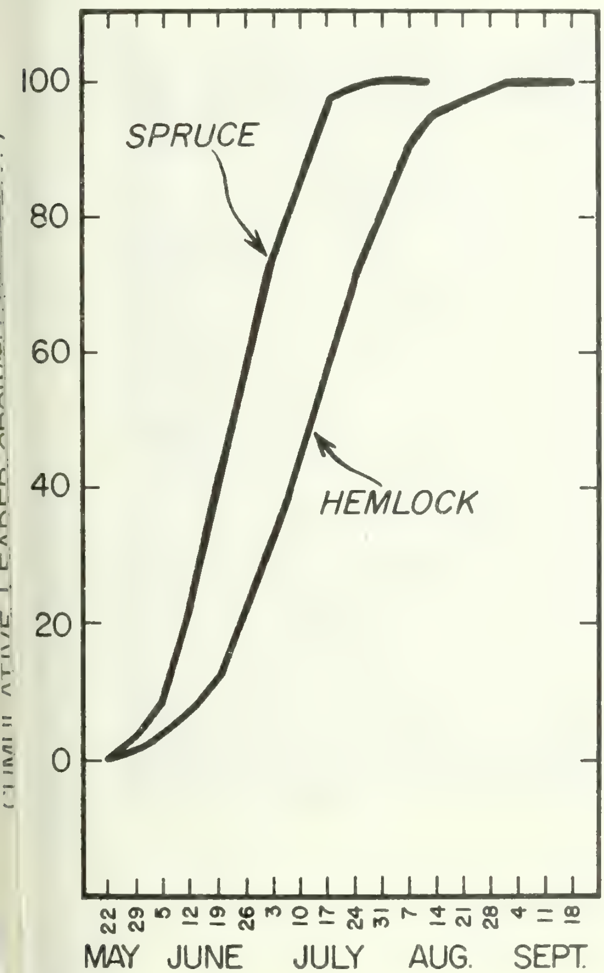

Figure 37.--Cumulative leader growth of spruce and hemlock, Hollis, Alaska, 1952 (adapted from Godman and Gregory 1955).

OWN CLOSURE

As soon as crowns of dominant and codominant saplings form a losed canopy, they begin to shade out understory vegetation. After a e years, the forest floor becomes almost devoid of shrubs and herbs fig. 38). Even tolerant hemlocks begin to die out, as part of the g trend from thousands to only a hundred or so trees per acre.

Age of crown closure varies with density of stocking. Osborn 168) measured the following percent closure of 9-year-old western

hemlock planted at different spacings near Haney, B.C.:

Spacing (feet)	Crown closure (percent)
3 by 3	58
6 by 6	41
9 by 9	29
12 by 12	19

Figure 38.--Forty years after clearcutting, the forest floor beneath this dense second-growth hemlock-spruce stand is almost devoid of shrubs and herbs. Virgin Bay, Alaska.

GROWTH AND YIELD ESTIMATES

Old-Growth Stands

Future yield for sites supporting old-growth, uneven-aged stan(cannot be predicted from direct measurements of site based on heigh and age of trees in the stand (Taylor 1933). Many dominant and cod(trees have been suppressed at one time. Age is difficult to determ: accurately. Trees over 300 years old virtually cease height growth so that height-age curves are inaccurate. Estimates of site produc in old-growth stands can best be obtained from examination of the soil. Preliminary soil-site relationships have been developed for southeast Alaska, based primarily on depth and drainage of soil and on parent material[8] (Stephens et al. 1969).

[8] F. R. Stephens, C. R. Gass, R. F. Billings, and D. E. Paulson. June 196 Soils and associated ecosystems of the Tongass. USDA For. Serv. Alaska Reg., dra rep., 67 p.

Taylor (1933) noted a reduction in site productivity with the increasing buildup of raw humus as stands approached climax. This buildup is reversed when the site is exposed to full sunlight after logging or destruction of the timber stand by wind or other catastrophe. Soil temperature increases, hastening decomposition of humus and lowering acidity of the soil. Growth of understory vegetation provides broad-leaved litter, generally beneficial to the soil. In short, the site is improved and, particularly, is more favorable for spruce.

High productivity of young-growth hemlock-spruce stands is a strong argument for harvesting old growth and establishing new stands. Average volume of old-growth climax stands in southeast Alaska is about 5,900 ft^3/acre (400 m^3/ha). Annual growth is offset by mortality so that net stand growth is zero (Hutchison and LaBau 1975). In contrast, young-growth stands on a 100-year rotation on an average site will produce about double the cubic-foot volume maintained in most old-growth stands (Taylor 1949). Annual net growth of all young-growth stands in southeast Alaska is 1.53 percent of their total volume (Hutchison and LaBau 1975).

Unthinned Even-Aged Stands

Yield tables for unthinned stands have been prepared for mixed hemlock-spruce and for pure stands of each species. The first tables were for hemlock in British Columbia (Province of British Columbia 1926). Then Taylor (1934) published yield tables for young-growth hemlock-spruce stands in southeast Alaska. These still are in use and are the basis for predicting productivity of the young growth that follows harvesting of southeast Alaska's overmature stands. For predicting productivity, Taylor used anamorphic techniques to develop proportional site index curves. His yield tables are for normally stocked stands. They are entered by site index and age, and, if the stand to be evaluated is less than normally stocked, tabulated values are adjusted downward. This may be done by comparing the basal area of the stand with that of a well-stocked stand as given in the tables. For example, if the stand has a basal area per acre 90 percent of normal, then tabular volumes should be reduced 10 percent.

In 1937 Meyer published yield tables for hemlock-spruce for the north Pacific coast. He used 300 of Taylor's plots from Alaska, 64 plots from British Columbia, and measured 294 new plots in Oregon and Washington. Meyer developed proportional site index curves that did not differ appreciably from those prepared by Taylor. He recognized that a high percentage of spruce in a stand increased the yield and so he provided tables to correct for variations in species composition. He judged the effect on site index to be minor and did not make an adjustment for this. He noted differences between the Oregon-Washington and Alaska data but balanced them to produce a single set of yield tables.

Almost concurrently, supplementary tables were published providing additional information for trees 6.6 in (17 cm) and more in diameter at breast height (Pacific Northwest Forest and Range Experiment Station 1937).

Subsequent use and evaluation of Meyer's tables indicated accurac could be improved by preparing separate tables for each species and geographic location.[9] Barnes (1962) did this for stands in which hem comprised at least 40 percent of the basal area; he used the same basic data as Meyers but discarded plots with over 60 percent spruce. He found that stands in Oregon and Washington of the same site and age had about 20 percent greater average diameters than stands in British Columbia and Alaska and even greater differences in volume. Apparentl young stands in northern areas are more dense at early ages, with earlier crown closure and more severe competition than stands in the south. Average heights of stands of the same age and site index were about 15 percent taller in Oregon and Washington than in British Columbia and Alaska. Because of these differences, Barnes prepared separate hemlock yield tables for each of the three areas. He also developed and presented in the same report a yield table using average stand diameter as the independent variable rather than site index and age.

Recently, Chambers and Wilson (1972) developed empirical yield tables for hemlock stands in western Washington. They are based on 232 sample plots in stands where the volume averaged 85-percent hemloc Site indices ranged from 87 to 232, based on Barnes' (1962) site inde curves. The tables are entered with site index and age. Tables are included for stands with less-than-normal basal area to facilitate yield predictions for stands not fully stocked. Also included are yield tables based on average stand diameter and basal area.

All these natural-stand yield tables give only net growth and ar not appropriate for intensive management where net growth plus thinni approaches gross growth (Curtis 1972). Their usefulness will diminis with time. Most prolonged use will be in Alaska where thinning is more expensive because accessibility to stands is limited and labor costs are high. Some stocking control treatment early in the rotation is now being done, however, and more is expected as timber values increase. Early thinning would alleviate the problem of small stem diameters caused by dense stocking and could greatly increase usable yield.

Several organizations are developing stand simulation models for projection and evaluation of stand growth and development under diffe management regimes. Lin (1970) developed a method for assessing available growing space of young western hemlock and a computer model for simulating stand growth. Research with other species has shown that growth response can be integrated with various thinning cycles, harvest cutting techniques, and estimated costs and returns as a basi for selecting management alternatives and developing management plans (Myers 1969, 1973, 1974). Myers (1971) also developed field and computer techniques for preparation of managed-stand yield tables.

Site-index curves for hemlock-spruce (Taylor 1934, Meyer 1937) a for hemlock alone (Barnes 1962) are available. Site index is based on height at age 100.

Wiley (1976) reported development of site-index tables for weste hemlock in western Washington, Oregon, and British Columbia. The

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[9] Robinson, Walter Lee. 1951. Application of western hemlock yield tables for Oregon and Washington to stands in Alaska and British Columbia. M.S. thesis, Oreg. State Coll. [Univ.], Corvallis, 54 p., illus.

tables differ from those currently available in that site index age is lowered from total age 100 years to breast-high age 50. Although based on plots representing coastal and inland situations, glaciated and nonglaciated soils, and high and low stand densities, tests showed no growth differences that would justify separate equations.

In Alaska, additional stem analyses of hemlock and spruce indicate that height growth differs from published site curves, the difference being greater for low sites than for high sites. The general shape of the curves apparently differs by soil series, and accuracy of yield predictions might be improved by development of different curves for major soil types (Harris and Farr 1974).

Even-Aged Thinned Stands

The only yield tables for managed stands presently available for emlock and spruce were developed by Bradley et al. (1966) for pure lantations of each species in Great Britain. Original tables were in mperial units, but the tables for western hemlock were converted to merican units of measure by Hoyer (1967); later, tables for both pecies were converted to metric units (Hamilton and Christie 1971). he tables are based on permanent plot records in Britain. They hould be used with caution in North America because of different nvironmental conditions and management practices. They do, however, rovide a general guide until local experience is available.

Several organizations are working on stand simulation models, anging from whole-stand models to single-tree-distance-dependent odels. A cooperative effort is currently underway between private ompanies and government agencies to pool information for western emlock and develop managed-stand yield tables for this species in regon and Washington.

PECIES TO MANAGE

Important gains in economic return may be made by proper selection f species. Most acres in the coastal fog belt will grow not only emlock and spruce in various proportions but also one or more associated species. Each species responds differently to variations in oil and other environmental factors, so for any given habitat there hould be a species or combination of species that will be more productive han all others. Also, there is genetic variation within a species, nd one genotype will do well in a given habitat whereas another will ot. There is considerable ecological justification for preferring tands of mixed species over stands of single species from the standpoint f resistance to insects and disease. Not enough is known about the pecies or the habitats to say what mix should be grown on each acre, ut there are some general guidelines.

In Oregon, Washington, and British Columbia forest managers often earcut hemlock-spruce, then plant Douglas-fir. Expecting hemlock nd some spruce to seed in to provide a mixed stand, they usually plant he fir at a wide spacing. Douglas-fir is thus extended westward into he hemlock-spruce type and usually replaces spruce in the dominant anopy. One reason for this practice is that the white pine weevil

repeatedly damages spruce. Damage is more severe in the drier easter part of the spruce range where hemlock-spruce merges into hemlock-fir Another reason is that fir seed and seedlings have been more readily available for planting than either spruce or hemlock. A third reason is that Douglas-fir timber values have been higher than those of heml or spruce, and this also provided justification for extending fir westward. In recent years, however, hemlock and spruce values have increased relative to fir; and what they will be a rotation ahead cannot be accurately predicted.

The best course of action may be to establish the species or species combination that will produce the most wood fiber. In Oregon and Washington, usually this will be hemlock-spruce, hemlock-fir, or perhaps pure hemlock. Smith (1962) hypothesized that a pure stand of the subordinate species of a stratified mixture--in our example weste hemlock--probably would be more productive than the mixture of which it could be a part. In areas along the ocean front affected by salt spray, the best species may be pure spruce. There are areas where on or more of the associated species will do well, such as red alder or western redcedar over a high water table or shore pine on maturing sand dunes.

In the transition zone between the hemlock-spruce and Douglas-fi forest types, hemlock-spruce generally is more productive than pure Douglas-fir. Meyer (1937) noted that 100-year site index 150 is common for hemlock-spruce in Oregon and Washington. Site index for Douglas-fir is slightly higher on the same areas, but Douglas-fir stands usually have fewer trees per acre. For cubic-foot volume in the 20- to 80-year age classes, he found hemlock-spruce productivity ranged from 22 to 41 percent more than Douglas-fir, depending on age and difference in site index (table 6). Other authors have calculate similar differences (Dimock 1958a, Hiley 1950). The superiority of hemlock-spruce, however, is questioned by Scott (1962) on the basis that hemlock's greater tolerance permits a larger proportion of total yield to remain alive than would be the case with Douglas-fir. Since most volume data are based on a single observation date, more of the Douglas-fir production could have been lost through mortality. When aboveground net primary biomass production was compared in stands of coastal hemlock-spruce and interior Douglas-fir, Grier (1976) found that production in a 26-year-old hemlock-spruce stand was 1.6 times that of Douglas-fir. Productivity of coastal hemlock-spruce appearec to decline more rapidly with age than did that of Douglas-fir. Briti yield tables show similar yields of hemlock, spruce, and fir (Hamiltc and Christie 1971).

Table 6--Comparison of hemlock-spruce and Douglas-fir volume, by site index (100-year basis), Oregon and Washington[1]

Age	Hemlock-spruce site index		Douglas-fir site index			
	150		150		160	
Years	ft^3/acre	m^3/ha	ft^3/acre	m^3/ha	ft^3/acre	m^3/ha
40	7,500	520	5,750	400	6,160	430
60	13,100	920	9,490	660	10,200	710
80	17,500	1 220	12,400	870	13,360	940

[1] Based on Meyer (1937).

Steinbrenner (1976) compared the yields of natural stands of estern hemlock and Douglas-fir growing on similar soil types in outhwest Washington. For nearly all soils, the site index of hemlock as lower than for Douglas-fir. Potential yields, however, averaged 3 percent higher for western hemlock than for Douglas-fir (table 7). iley (1976) showed that not only can hemlock stands carry more trees er acre than Douglas-fir for a given average d.b.h. but also hemlock ontains more volume than Douglas-fir of the same diameter and height.

Table 7 (reproduced from Steinbrenner 1976, with permission)--

Douglas-Fir and Western Hemlock/Coastal Soils

YIELDS OF NATURAL STANDS

Soil Series	Extent (M Acres)	Douglas-Fir Site Index (Feet)	Douglas-Fir MAI (Cu. Ft.)	Hemlock Site Index (Feet)	Hemlock MAI (Cu. Ft.)
Arctic	35	130	248	120	356
Astoria	80	140	285	110	318
Capps	20	120	222	110	318
Dahlia	25	130	248	110	318
Impie	45	130	248	120	356
Knappton	40	110	198	110	318
Lytell	42	140	285	110	318
Mopang	28	130	248	110	318
Price	44	130	248	120	356
Willapa	44	120	222	110	318
	403				
Weighted Average:		130	248	113	329

Total Yield (M Cunits)		
Douglas-Fir	999	
Hemlock	1,326	
Difference	327	(+33%)

Little is known about the productivity of the Douglas-fir and hmlock mixture. Because of hemlock's tolerance for shade and ability t utilize light filtering through the dominant canopy, one may hypothesze that the mixture is more productive than Douglas-fir alone. Aso, the mixture of the two species with differing root systems may uilize soil nutrients and moisture better than fir could do alone. Rplacement of Sitka spruce by Douglas-fir appears to be a reasonable mnagement alternative toward the south on sites where Douglas-fir wll do well, especially where the white pine weevil is a problem.

Westward from the transition zone and approaching the coastline, ste index of Douglas-fir drops off relative to hemlock-spruce and tis increases the productivity differential favoring the coastal secies. Here, it would be better to establish hemlock-spruce or, i areas where white pine weevil is a problem, hemlock alone.

Westward limits for Douglas-fir are related to soil type; site index is generally better on coarse-textured soils than on fine-textured soils. For example, near Sand Lake, Oregon, Douglas-fir grows well almost to the beach on sandy soils. On finer textured soils north and south of Sand Lake, it usually drops out of the stand well back from the beach.

On the east side of the transition zone, care should be taken to avoid planting Sitka spruce where its site index is low relative to hemlock-fir and where susceptibility to weevil damage is high.

In Alaska, Taylor (1929, 1934) found young-growth stands with a mixture of hemlock and spruce more productive than pure stands of either species. Dense hemlock thickets tend to grow slowly on poor sites. An undisturbed layer of raw humus favors establishment of hemlo Spruce is favored by disturbing the humus layer or mixing it with mineral soil. A mixture of hemlock in the intermediate and suppress crown classes utilizes light otherwise lost or utilized only by undet vegetation. The hemlock also shades out lower spruce branches and retards growth of epicormic branches.

Red alder initially grows more rapidly than hemlock-spruce and, on a very short rotation, would be a viable alternative as a species to manage. Berntsen (1961) compared alder and conifer stands on the Oregon coast and found that at age 20 alder stands had double the volume of Douglas-fir stands but that by age 30 the growth rate of fi surpassed that of alder and thereafter continued to forge ahead.

Zavitkovski and Stevens (1972) reported the maximum growth peri for alder as age 10 to 15 years and recommended that best yields wou result from harvesting before 20 years of age. DeBell (1972), Smith and DeBell (1973, 1974), and DeBell et al. (1978) pointed out some effects of stand density on yield of alder and opportunities for sho rotation culture. Experience in British Columbia points to the poss bilities for capitalizing on the fast early growth of red alder and for improving yield through early thinning (Warrack 1964, Smith 1978 Short rotation culture is still considered impractical; so in Oregon and Washington general practice is to minimize alder encroachment on conifer sites by application of herbicidal sprays. Yoho et al. (196 analyzed the economics of converting young alder to Douglas-fir and concluded that in most cases it was advisable to make the conversion A similar conversion to hemlock-spruce also appears economical and i being accomplished on a large scale in the coastal areas of Oregon and Washington (Dimock et al. 1976a).

Systematic attempts are being made in some areas to select spec based on known ecological requirements of tree species and on site conditions. For example, the British Columbia Forest Service is developing guidelines for selection of tree species for use in the Vancouver Forest District based on soil moisture, nutrient regime, a indicator plants (Johnson 1977).

The most productive species may not be the best one to manage i market demand is low. Also, the most productive species may be diff to manage under harvest cutting restraints imposed by other uses of the area, or a productive species may be particularly susceptible to an insect or a disease. It is up to the forest manager to balance t biological, economic, social, and esthetic factors and decide the best species or species combinations to grow.

ROTATION

The optimum rotation age for management of hemlock-spruce depends on the objectives of the landowner. Large industrial holdings usually are managed for maximum economic return. Some small ownerships have this objective, but others are managed for esthetic and recreational values, shelter for wildlife, or other purposes. On public land a common objective is to produce a large yield of high quality sawtimber, and the rotation age is often set beyond the culmination of the mean annual increment curve for sawtimber. Almost invariably there is a mix of objectives, so the manager of public lands, faced with overlapping and often conflicting objectives, must make compromises and select the rotation that provides the greatest overall benefits. The manager may vary rotation age from place to place as objectives differ within the ownership--a long rotation for some public use areas and a shorter one for timber production areas.

There is an overall trend to harvest trees at younger ages, but within this trend rotations vary widely. At the upper extreme are recreation areas, often managed under the selection system, where generally only overmature trees are harvested to maintain esthetic values and public safety. At the other extreme the private owner, needing current income, may harvest as soon as the trees are large enough that market value substantially exceeds logging costs. Many hemlock-spruce forests are managed as even-aged stands on an economic rotation that varies from about 40 years in intensively managed areas to well over 100 years in less accessible areas.

Several factors serve to lengthen or shorten economic rotation length. Of particular importance is the landowner's alternative rate of return. If it is high, the interest on capital invested in growing stock is high and the rotation is shortened. A high interest rate also lowers the present net worth of the land, thereby having an opposite but usually lesser effect. Wood value per cubic foot increases with log size, and large timber is less costly per unit to harvest than small timber; both factors tend to lengthen the rotation by increasing the value. Commercial thinning, if gross increment is little affected, increases rotation age by concentrating growth on fewer trees and thereby reduces the capital investment in growing stock. Optimum rotations are shorter on good sites than on poor sites (Pearse 1966, Grayson and Johnston 1970).

The economic rotation is often adjusted to better coordinate timber production with other uses of the land. A common example is lengthened rotations to meet esthetic or landscape management objectives on National Forest land. Other adjustments are made to maintain an even flow of raw material into the local economy, accelerate harvest in decadent stands to capture mortality, produce logs of a particular average diameter, respond to changing market demand, and meet needs for capital elsewhere in the organization.

Rotation age plays a particularly important role in determining the allowable cut in areas with a preponderance of old-growth timber. The policy on most ownerships has been to extend harvest of overmature stands so that by the time harvest is completed young growth will have reached rotation age and timber harvest may continue without idling utilization plants and disrupting the local economy. Shortening the rotation age shortens the conversion period and permits increases in the allowable cut.

Most rotations currently in use on National Forests are termed standard sawtimber rotations and in reality are between a rotation based on culmination of the mean annual increment curve for sawtimber and a strictly economic rotation (McGuire 1976).

TIMBER MEASUREMENT

Meyer (1937) prepared volume tables to be used for spruce and hemlock in Oregon and Washington. These tables remained in use for many years. The spruce tables require entry of diameter data inside bark at 18 ft (5.5 m). This measurement avoids the butt swell in old-growth spruce but is a dimension hard to obtain; the tables are not appropriate for young-growth trees with little butt swell because they tend to overestimate volumes of small trees.

In Oregon, Washington, and Alaska, for many years the USDA Forest Service has used board-foot volume tables based on diameter, total height, and form class (Bruce and Girard n.d., Girard and Bruce n.d.)

Browne (1962) prepared cubic-foot volume tables for British Columbia. The basic tables give total tree volume including stump and top. Supplementary tables provide correction factors that enable the user to derive merchantable volume based on three different utilizati standards. Local height curves must be developed before the tables are used for management-unit surveys or timber sale cruises, and it is desirable to develop local corrections for tree form and utilizati standards. Corrections for defect must also be made.

Fligg and Breadon (1959), working with a subsample of data collec for the British Columbia cubic-foot volume tables, prepared log-position volume tables for hemlock and spruce. These tables provide cubic-foo volume estimates of individual logs. Also available are tables for conversion of stump diameters to diameter breast high (British Columb Forest Service 1966).

Volume tables for use in southeast Alaska are available for old-growth western hemlock and Sitka spruce (Bones 1968), old-growth cedar (Farr and LaBau 1971), and for young-growth hemlock and spruce (Embry and Haack 1965, Farr and LaBau 1976). In addition, tables are available for estimating volumes by log positions (Bones 1963) and fo estimating diameter at breast height from stump diameter (Bones 1961 Volume tables for old-growth hemlock and spruce in south-central Alaska are also available (Haack 1963).

Johnson and Hartman (1972) reported the development of fall, bu and scale cruising, in which sample trees are felled and measured in the woods and used to estimate total sale volume. This method eliminates many of the problems of estimating total or merchantable height, tree taper, bark thickness, and defect. The sampling error can be controlled by sample size. Fall, buck, and scale cruising is being used on most timber sales in Alaska.

A major difficulty in timber cruising is estimating the amount defect in the tree. Defect normally increases with tree age, and it estimation is a problem in the old-growth stands of British Columbia and southeast Alaska. In southeast Alaska, Kimmey (1956) developed factors relating species, diameter, and position of visible indicato

o percentages of decay in standing hemlock, spruce, and cedar. His ables have been revised (Farr et al. 1976). They are useful for xtensive surveys but are often in error for small sales. In British Columbia, tables and equations to predict decay in standing trees have lso been developed (Bier and Foster 1946a, 1946b; Bier et al. 1946; oster and Foster 1952; Browne 1956; Foster 1957).

A recommended approach for determining recovery for hemlock-spruce nd other Pacific Northwest species is to determine cubic volume as he basic measurement of the available wood fiber, then to convert t to estimates of lumber recovery in board feet, plywood in square eet, chips in tons, and other appropriate end products. Usually he conversion will require information on diameter and grade of logs nd percentage and type of defect. Conversions to several end products an be made to see which will provide the greatest economic return David Bruce, Pacific Northwest Forest and Range Experiment Station, ersonal communication).

PROTECTING THE SOIL

Productive capacity of the forest ecosystem depends primarily on he basic soil resource. The soil mantle serves as a storage and egulating medium for water production, provides direct support and nchorage for plants, and serves as a medium for storage and exchange f nutrients. Damage to the soil can directly affect trees through estruction or degradation of the site. Indirect damage to other esources can be even more disastrous.

Care must be taken to protect the physical structure, water-holding capacity, and nutrient capital of the soil through application of proper management practices. In addition, soil classification and mapping, along with identification of potential hazard situations, should be required as part of any timber management activity.

Timber management activities directly affect soils by disturbance during logging and roadbuilding and through changes in vegetation. Forest residues and their treatment and eventual incorporation into the soil further affect the soil.

The surface of the mineral soil should be protected from the impact of raindrops and other disturbance. Usually the forest canopy and the litter layer of needles and small twigs on the forest floor are sufficient protection. When trees are removed during logging, some of the litter may be scraped away. Depending on the degree of aggregation in the surface soil, exposed soil particles may be dislodged by the splash of raindrops and may plug pore openings. This reduces the infiltration rate and increases the possibility of surface runoff. Surface water picks up still more soil particles which seal off additional pore spaces, and erosion may result. Coastal soils vary widely in erodibility. Exposure that may be inconsequential with some soils may be disastrous with others. Soils developed on recently stabilized beaches, flood plains, and sand dunes are very subject to erosion if exposed.

Forest residues can serve as a substitute mantle, protecting the soil, especially on steep slopes where disturbance is difficult to avoid and the potential for erosion is great. Part or all of the

residues should be left on such areas to protect the soil. Together with shrubs and herbs, they hold back downhill movement of soil during winter storms.

Residues affect the physical properties of underlying soils. As they decay, the organic compounds in the surface soil often cause aggregation of fine soil particles and this usually improves the water infiltration rate (Rothacher and Lopushinsky 1974). Shade afforded by residues reduces evaporation from the soil surface. Operation of machinery over the surface will, under wet conditions, compact the soil and reduce infiltration rate, permeability, and gaseous exchange. Thus, machine piling of residues to reduce fire hazard or for seedling establishment may also have adverse effects.

EFFECTS OF BURNING ON THE SOIL

Effects on the soil caused by burning residues depend on the kind of soil, intensity and duration of the fire, topography, weather conditions, and many other factors. There is considerable literature on burning effects, but little of it pertains directly to moist hemlock-spruce situations. What does apply mostly concerns the southern portion of the range.

In coastal Oregon, Morris (1970) found that actual exposure of mineral soil after controlled broadcast burning is quite limited. Intensity of burn on sample plots by percentages was: light, 75.2; moderate, 14.2; severe, 0.1; and unburned, 10.5.

After burning, most of the surface is left with a charred but protective mat of organic material to receive the initial impact of raindrops (fig. 39). Morris' study was in the drier portion of the hemlock-spruce range. In the more moist situations farther north, burning is less likely to consume protective forest floor material. Fahnestock examined a 110-acre (44.5-ha) wildfire area on Chichagof Island, Alaska, and found no areas of hard-burned soil.[10/] Rapid development of herbaceous and shrubby vegetation and establishment of tree seedlings provide additional protection throughout the hemlock-spruce type.

Austin and Baisinger (1955) pooled data from moderately burned and hard-burned areas and concluded that burning substantially reduced the organic matter content and moisture-holding capacity of the top 0.5 in (1.3 cm) of soil. Effects were much less in the 2-in (5-cm) layer and insignificant in the 6- to 12-in (15- to 30-cm) layer. Tarrant (1956) also compared physical properties of soil from unburned, lightly burned, and severely burned areas. Soils under lightly burned slash had less macroscopic pore volume, more microscopic pore volume, about the same percolation rate in sandy clay loam, and greater percolation rate in pumiceous sandy loam. Total pore volume and bulk density were about the same. Severe burning had more detrimental effects on soil; but with only 0.1 percent of the soil in this category, the total effect was insignificant. Water-repellent properties of soils may be

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[10/] Fahnestock, George R. 1970 forest residues. Memorandum to the files, August 12, 1970, on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Figure 39.--Broadcast burning generally leaves a charred mat of organic material which receives the initial impact of raindrops and protects the underlying soil from erosion. July, after a spring burn, Oregon coast.

creased by burning, thereby reducing the infiltration rate (DeBano al. 1970). Light burning apparently has little effect on the ng-term geologic process of soil formation (Moore and Norris 1974).

In general, the main physical effect of broadcast burning on hmlock-spruce forest soils in the southern part of the range is creased exposure of mineral soil. This improves the potential fr regeneration, also the potential for erosion. But a prescribed brn normally exposes only a small portion of the soil, most of the efect being limited to the forest floor material itself (Morris 1970). Te effect can be controlled to some extent by proper timing of the brn. Generally, erosion caused by burning of residues is limited to secial topographic and soil situations. Potential for erosion is ually highest on steep slopes but may be high on gentle slopes with erodible soils. Soils developed on recently stabilized sand dunes a particularly subject to erosion if the subsoil is exposed.

Burning also affects soil flora and fauna, but specific effects i hemlock-spruce forests are little known. Information from other aas indicates that burning causes no major qualitative changes in coposition, and capacity for rapid recovery is great (Jorgensen and Hoges 1970, Metz and Farrier 1971).

Forest residues serve as a storehouse for an important part of the nutrient capital on many hemlock-spruce sites. Depending on the residue volume and fertility of the underlying mineral soil, they contain variable proportions of the total nutrient supply. The proportion is higher in the north where thick accumulations of mor humus occur, lower in the south where residues decay more rapidly and are incorporated into the soil. Part of the nutrient capital is hauled out of the forest as logs, but the nutrient-rich leaves and twigs are scattered about as part of the forest residue (Cole et al. 1967).

A major effect of burning on nutrition is on timing of nutrient availability for tree growth. Nutrients are released during combustion and, except for nitrogen, most are left in the ash. Subsequent rains leach these nutrients into the soil where, in part, they become available for uptake by plants. Thus, nutrients accumulated over a period of many years are made quickly available. This quick availability is at the expense of slow release of nutrients through decay. Which schedule is more favorable for tree nutrition is not known. The burst of nutrients often contributes to a lush growth of herbs and brush which compete with tree seedlings for light, moisture, and accumulated released nutrients. These nutrients must be recycled and again made available for uptake as trees become dominant and their nutritional demands increase.

Research in other forest types has shown that some of the nutrient capital in forest residues is lost from the site during and after burning. In particular, much of the nitrogen is volatilized during combustion and lost into the atmosphere. This reduces the total amount of the nitrogen capital of the site. Nitrogen concentration of the residual material may be increased because of accelerated nitrogen-fixing activity in the soil, so that after a few years the surface soil may have as much nitrogen as an area that was not burned (Grier 1972, Wells 1971, Jorgensen and Wells 1971, DeBell and Ralston 1970, Knight 1966). This increase, however may be misleading when the long-term effects on the site are considered. Losses of other elements during burning are less. Although some ash is carried away on convection currents during the fire (Knight 1966, Allen 1964, Grier 1972), the greater potential for loss is for nutrients in the ash to be leached or eroded away before they can be utilized by plants. Leaching tends to be more rapid in coarse, sandy soils than in fine soils. Nitrogen also may be lost from a site by leaching, and this increases after burning (Fredriksen 1971).

Calcium and other salts included in the leachate make the soil more alkaline, a condition favoring competing vegetation more than conifers. This alkalinity is short lived, however (Austin and Baisinger 1955, Tarrant 1956). Coastal soils with an average pH of 7.1 immediately after burning averaged 4 years later a near-normal pH of 4.6. This compares with nearby unburned soils where the pH ranged from 4.3 to 4.5 during the same period.

Stephens (1969) found that organic matter rather than clay is the source of almost all the cation-exchange capacity of soils in coastal Alaska. Thus, a reduction in organic matter by burning could have adverse long-term effects on tree growth. On the other hand, Stephens et al. (1969) found that stands that originated after wildfire did not differ significantly in growth rate from stands originating after

logging. On immature soils--such as alluvium, glacial outwash, or till--care should be taken to preserve the surface organic layer as a source of nutrient capital and to reduce erosion.

The main nutritional effects of burning hemlock-spruce logging residues seem to be increased availability of mineral nutrients and short-term losses of nitrogen. Burning never adds to the nutrient capital of an ecosystem. It volatizes nitrogen and creates the potential for loss of other nutrients. More research is needed on relationships between residue treatment and tree nutrition.

SOIL MASS MOVEMENT

Landslides are common on steep slopes throughout the hemlock-spruce type. They are a form of mass wasting or soil mass movement and can be classified on the basis of material, depth of movement, and character of the failed surface (Sharpe 1938, Eckel 1958). In the hemlock-spruce type, the most widespread mass wasting includes debris slides, debris avalanches, debris flows, and debris torrents. All of these involve initial failure of a relatively shallow cohesionless soil mass on steep slopes above an impermeable layer (Swanston 1974b).

Studies indicate that the critical slope angle corresponding to the average angle of internal friction (angle of repose) for glacial till soils is 37°. An estimated average critical angle for colluvial soils is 36° (Swanston 1974a). The lower limit of critical internal friction angles for these soils is about 34°. Slopes with gradients equal to or greater than this angle are highly susceptible to slides, particularly if they are severely disturbed (Swanston 1969).

The angle of repose for soils commonly found on slopes in southeast Alaska varies from about 34° to 46°, depending on soil density and weight of overlying material (Swanston 1967a). Slope stability is also conditioned by such factors as anchoring by root systems, cohesion provided by organic colloids, bedrock structure, and moisture content.

Landslide tracks are common throughout southeast Alaska. More than 3,800 large-scale debris avalanches and flows have been counted on aerial photographs of the Tongass Forest (data on file, Forestry Sciences Laboratory, Juneau, Alaska).

Mass erosion was not considered a serious forest management problem in southeast Alaska before large-scale clearcutting was begun in the mid-1950's. Nothing could be done about landslides in the natural environment, and there was no experience to demonstrate what might happen after extensive logging. After heavy rains in October 1961, severe mass movement occurred in several locations. In Maybeso Valley, comparison of aerial photos taken before and after logging showed that 1 sizable landslides occurred in the 100 years before logging. In contrast, 116 slides occurred within 9 years after logging (Bishop and Stevens 1964). As a result, in addition to possible stream siltation, productive timberland was removed from production. On one study area, 1 percent of regeneration study plots were temporarily or permanently removed from timber production (Harris 1967).

Mechanics of debris avalanching has been described quantitative
(Swanston 1970).

Vegetative cover helps to stabilize steep mountain slopes. Whe
cover is disturbed, the probability of mass movement of soil increas
(fig. 40). Damage is extensive as the downslope movement of materia
often removes all vegetation and soil material in its path. Regrowt
may take years as development of new soil is a slow process and slou
of material may continue in the slide track. Landslides caused by
people are also objectionable from an esthetic standpoint.

Extensive investigation of soil mass movement has been done in southeast Alaska (Bishop and Stevens 1964; Swanston 1967a, 1967b, 1969, 1970, 1971, 1974a). In Washington, the effects of landslides and associated siltation of salmon and trout streams has also been studied (Cederholm and Lestelle 1974, Fiksdal 1974).

Figure 40.--Soil stability may decrease after clearcutting on steep slopes, such as in this steep V-notch ravine, Maybeso Valley, Alaska.

In western Washington, landslides also occur as a result of heavy rains, often associated with snowmelt. Such heavy runoffs may occur during a chinook, a sudden warm onshore flow of marine air accompanied by heavy rainfall. When they do, severe damage can result. For example, in January 1972 during a 48-hour period, the Longview, Washington, area received over 12 in (30 cm) of rain and a large snowmelt. As a result many slides and much damage occurred (Sommer 1973).

Human activities, such as roadbuilding, play an important part in triggering slides or increasing their frequency. For example, massive failures of sidecast material occurring in May 1971

contributed heavily to the sediment load of Stequaleho Creek, a tributary of the Clearwater River on the Olympic Peninsula, Washington. In this area a study showed that in the previous 84-year period both natural sliding events and those caused by people contributed to sediment in streams. Events caused by people occurred at the rate of 13.3 per year compared with 0.3 per year for natural events. On an annual basis, events related to roadbuilding caused a volume movement of 11,400 yd^3 (8 700 m^3) of material compared with 1,800 yd^3 (1 400 m^3) related to natural events (Fiksdal 1974).

Logging residues can also cause soil loss and stream sedimentation vhen they contribute to debris torrents. These may be caused when soil material from short debris avalanches in steep gullies accumulates behind logs and debris, forming temporary dams. During high water, these dams can wash out, starting a debris torrent that collects lownstream debris and soil as it goes and scours the channel clean for considerable distances. Flows may continue for a mile or more, stopping vhere the streambed levels off or continuing to deposit material into he next large stream below. On logging areas, accumulation of branches nd other residues in stream channels accelerates the process. The roblem is most common in areas of high rainfall and in steep "V-notch" avines (Swanston 1974a, Bishop and Stevens 1964) (fig. 41). Gradient f these streams is usually too steep to allow use by fish; however, ebris and sediment may be carried downstream to lower gradient stream ections used by fish.

The most practical management policy has been to avoid logging in reas of maximum susceptibility to slides--that is, slopes of approximatel 4° or more (Swanston 1969). Slopes with gradients equal to or greater han this may be highly susceptible to slides, particularly if greatly isturbed. In Alaska, the Forest Service's present policy is to avoid oad construction or logging on these areas until methods that do not amage the soil can be developed. Timber on slopes greater than 37° s excluded from the regulated cut[11/].

In the future, it may be possible to safely log on steep, slide-prone lopes. Skyline, balloon, and helicopter logging systems will greatly educe site disturbance. Whether avoiding soil disturbance will liminate the problem remains to be demonstrated. Tree root systems ay be extremely important in maintaining slope stability. If trees re the major stabilizing force on steep slopes, then clearcutting by ny method might still result in significant landslide activity.

The use of alternative silvicultural systems, such as some form selection or shelterwood, might allow logging on steep slopes. Use either system might be uneconomic now, especially in Alaska; but a ore favorable economic climate in the future could make such timber rvest possible. Before this, however, research is needed to evaluate rious alternatives for management of forests on slide-prone slopes. osts and benefits of various practices should be quantified.

[11/] Forest Service Manual R-10 Supplement 126, Title 2400--Timber Management, Nvember 1972.

Figure 41.--Debris-mud flow from a steep ravine, Maybeso Valley, Prince of Wales Island, Alaska: Upper photo, Debris-choked stream channel before flushing; lower photo, debris deposit on gentle topography.

PROTECTING THE FOREST

Trees, like other living organisms, are subject to aging and eventual death--natural processes in the renewal and continuation of the forest. As individual trees die, they make way for others and their remains are incorporated into the soil to provide nutrients for future generations. In nature, living (biotic) and nonliving (abiotic) agents alter the natural aging and death processes of trees and stands.

Biotic agents include disease-causing organisms, insects, nematodes, parasitic plants, birds, and mammals including man. Abiotic agents include wind, fire, landslides, floods, tidal waves, earthquakes. A single agent or a combination of agents may be responsible for a tree's death.

When destructive agents interfere with people's use of the forest, they become a problem. When forests are managed for timber production, fish and wildlife habitat, recreation, watershed protection, esthetics, or other uses, economic or social loss may result from the natural process of forest destruction.

The pattern of death of trees in a stand determines to a large xtent the character of the succeeding forest. For example, when all rees in a stand are blown down, killed by fire, removed by landslides, r clearcut by man, the natural process of renewal usually results in evelopment of an even-aged stand. When individual trees die as a esult of attack by insects, disease, animals, or from selection utting, an all-aged stand tends to follow. Trees decline in vigor s the natural aging process takes place, and the ultimate cause of eath may be difficult or impossible to determine.

Some destructive agents are more important in all-aged climax tands, and others are more important in even-aged stands. The relative mportance of each may change with stand age. Disease is perhaps the east spectacular in visual damage but accounts for much economic loss hrough death of valuable timber and, perhaps of more importance, loss f potential growth that may go virtually unnoticed.

Within the hemlock-spruce type, the importance of destructive gents varies by location. For example, fire is more important toward he southern portion of the range, especially in drier situations. On he other hand, fluting, which damages but apparently does not kill estern hemlock, is restricted to the northern portions of the type.

Silvicultural techniques used to manage stands can influence the usceptibility of trees and stands to damage by various agents. he forest manager should take this into account and must be aware of otential damage and be ready to adjust management techniques as xperience dictates. An excellent review of forest protection as it elates to western hemlock is available (Hart and Driver 1970).

A discussion of some damaging agents of the more important commercial tree species within the hemlock-spruce type follows. They ry in importance and amenability to management. For example, infection dwarf mistletoe causes loss of growth on hemlock, but it can be ontrolled through proper silvicultural practices. Wind also causes rious losses which can be reduced but not entirely prevented.

Damaging agents will be discussed in various detail, depending on importance, available knowledge, and degree to which silvicultural practices may prevent losses.

FIRE

Fire can be a serious destructive agent within the hemlock-spruce type, but far less serious than it is farther inland. Greatest danger from fire is in the south. In Oregon, Washington, and on Vancouver Island fire danger increases rapidly inland from the beach, coinciding with reduced summer fog. Aspect also affects fire danger. In many valleys oriented east and west, south-facing slopes have experienced a higher frequency of fire than the north-facing slopes (Schmidt 1960).

Fire has affected both species composition and age structure of the coastal forest. Where fire has been common, extensive even-aged stands are found, many dating from fires caused by people during the period of white settlement. In contrast, Alaska hemlock-spruce forests are generally older and uneven-aged, although extensive even-aged stands do occur.

Fire is an important factor in controlling the distribution of Douglas-fir, and the species is likely to be a more important component of coastal forests in areas having frequent fires. The absence of Douglas-fir on the coast north of Kemano, B.C. (lat. 53°30'), appears to be owing to infrequent fires (Schmidt 1960).

Extensive fires have occured within the hemlock-spruce type. Morris (1934) has provided a good summary of recorded fire history for western Washington and western Oregon from the early 1800's to the Tillamook fire of 1933. During this period, fire was a common occurrence. Much of the area was uninhabitated, and reburns were common. It is difficult to reconstruct an exact fire history, but certain years stand out as especially severe. Particularly destructive fires occurred between 1845 and 1849 in Oregon's Nestucca Bay area and elsewhere in Oregon. In 1868 an extreme number of fires burned from Oregon to British Columbia. Schmidt's (1970) history of presettlement fires on Vancouver Island also reveals a long sequence of major fires. Much of this area, however, lay outside the hemlock-spruce type.

Fires on the Queen Charlotte Islands, British Columbia, have been mainly confined to rain-shadow areas on the eastern portion of the islands, receiving less than 60 in (150 cm) of annual precipitation.[12/]

In southeast Alaska, extensive fires have occurred in the past; but since 1900, few have been larger than 100 acres (40 ha). Fire does not play an important role in the management of coastal Alaska forests. Summers are generally moist and cool; dry periods last only a week or 10 days. Dry periods of 2 weeks or more with above normal temperatures occur every few years; but during recent dry summers, there have been few large fires. Lightning is rare in coastal Alaska, and fires are almost entirely caused by people. Permanent residents, transients, recreationists, contractors, and others share the responsibility (Noste 1969).

With low fire risk, it has not been necessary to burn logging residues. Most fires occur in connection with logging or logging

[12/] Personal communication from R. L. Schmidt, B. C. Forest Service, Victoria, B.C., June 1977.

amps, and operators are required to maintain fire equipment at all imes. During occasional summer dry periods, they may be required to lter working hours or suspend work. On National Forest lands in laska, limiting clearcuts to 160 acres (65 ha) further reduces hazards.

The Forest Service does not maintain a fire-suppression force in oastal Alaska, but standing agreements permit rapid airlifting of rews and equipment from the lower 48 States and interior Alaska if eeded. As more use is made of the forests in coastal Alaska, the isk of fire will increase. Disastrous fire years will no doubt occur n the future as they have in the past.

Fire danger from accumulation and exposure of forest residues is f definite concern in the hemlock-spruce type, although less so than n drier forest types. The greater concern is in the southern part of he range. Throughout the range, however, there is always a danger of ildfire starting in forest residues.

In Oregon and Washington, fire has been an important consideration n management of the hemlock-spruce type, particularly inland in the ransition zone toward hemlock or Douglas-fir forests. Slash burning o reduce fire hazard has been the rule wherever conditions were dry nough to permit burning. Now, however, decisions to burn tend to be ade to fit individual circumstances. Often the need to reduce hazard s less today because of better utilization and harvesting small utting units. The problem of pollution from smoke has caused a evaluation of the need for burning. Fire regulations in each State d most timber sale contracts require felling of snags and unmerchantable ees on clearcut areas, primarily to reduce fire hazard.

Public land managers are often faced with increased fire risk due t heavy public use, and this has tended to favor burning. Private ndowners may simply restrict use of their land during periods of gh danger.

Generally in the hemlock-spruce type in Oregon and Washington, te trend is away from slash burning because of better utilization, re cutting in young even-aged stands with less defect, problems with ar pollution, and the greater value of western hemlock and, hence, ss conversion to Douglas-fir.

AIMAL DAMAGE

Mammals and some birds destroy seeds and damage trees and stands wthin the hemlock-spruce type. In the unmanaged forest, the influence o mammals is merely part of the normal ecological process. In some cses people may place a higher value on the animals involved than on t trees or other plants "damaged." This fact is becoming especially iportant as demand for outdoor recreation increases; however, when frests are managed for production of wood, fiber, or other products drived from trees, animal damage may become a problem (Crouch 1969, Bck et al. 1969, Dimock and Black 1969). Evans (1969) has reviewed dage from wildlife as it affects management of western hemlock.

Mice, voles, and shrews of various species are common on forested ad cutover land throughout the hemlock-spruce type (Klein 1965, Maville and Young 1965, McGregor 1958, Meehan 1974, Moore 1940).

Although they were considered a potential problem at one time (James 1956), they have apparently not prevented natural regeneration on cutover areas (Harris 1968). They do consume considerable amounts o tree seed and where they cannot be controlled by pesticides have largely eliminated direct seeding as an artificial regeneration prac

In British Columbia, damage from squirrels gnawing the inner ba of western hemlock has been reported (Buckland 1952). Usually squir damage is restricted to small areas, but in one case some 5,700 acre (2 300 ha) on Tournour Island in Johnson Strait were affected. Tree from 8 to 80 years old were damaged. Complete girdling was rare, but decay is reported to have entered through 30 to 70 percent of scars.

Both elk and deer damage trees within the hemlock-spruce type, but little specific information is available on extent of damage. E browse conifer seedlings and may damage plantations by trampling seedlings while grazing on clearcut areas. According to Harper (196 damage peaks from 6 to 8 years after logging and lessens thereafter. Damage is greatest near timber and diminishes as the distance from standing timber increases. Elk have apparently eliminated some plan species in creek bottoms on the Olympic Peninsula and undoubtedly pl an important role in plant succession on alluvial bottom-land sites (Franklin and Dyrness 1973, Sharpe 1956).

According to replies to questionnaires from Forest Service lanc managers, deer are the most troublesome animals on National Forests the Pacific Northwest (Crouch 1969). Deer readily browse conifer seedlings. Browsing slows the growth of seedlings and may kill youn or newly planted seedlings (Black et al. 1969).

Species preference is not clearly known. In some areas of weste Washington and Oregon, browsing by deer has retarded Douglas-fir anc allowed western hemlock to dominate the sites (Mitchell 1950). Cowa (1945) reported that deer preferred Douglas-fir over western hemlock and suggested planting hemlock in portions of southern Vancouver Island where browsing was a problem. On the other hand, Brown (1961 found that western hemlock was preferred over Douglas-fir. Western redcedar appears to be preferred in the Queen Charlotte Islands to t point where cedar regeneration has been eliminated in some locations In Alaska browse preferences are not known and deer are not now considered a problem in reforestation.

Efforts to control damage involve use of barriers that prevent browsing or use of chemical repellants that discourage browsing. Plastic mesh tubing (Campbell 1969, Campbell and Evans 1975) is bei used to protect Douglas-fir seedlings in Oregon and Washington with some success (fig. 42). Chemical repellants have been tried over t years with varying success (Evans 1974, Rochelle et al. 1974).

Some protection from browsing may be obtained by leaving loggi residues on the ground rather than burning them (Crouch 1968, Gocke 1966). Planting of very large seedlings--up to 5 ft (1.5 m) in height--may reduce their susceptibility to browsing (Hartwell 1973, Hines 1973); and when browsed, large seedlings may recover more readily than small ones (Newton 1973). Selection of less palatable genotypes shows promise (Dimock 1974, Dimock et al. 1976b).

Figure 42.--Plastic-mesh tubing on Douglas-fir seedling to protect it from browsing. Quinault, Washington.

gure 43.--Inspection of ouglas-fir branch clipped y mountain beaver, Quinault, ashington.

Increasing the size of clearcuts may reduce damage. Smith and Walters (1965) noted that damage to planted Douglas-fir on Vancouver Island was concentrated in clearcut areas that seldom exceeded 2 acres (0.8 ha).

Mountain beavers (*Aplodontia rufa*) or "boomers," as they are known locally, are an important cause of damage to conifer plantations in portions of the hemlock-spruce type (Munger 1943, King 1958, Crouch 1969, Lawrence et al. 1961). The animals range along the Pacific coast from northern California to British Columbia. The mountain beaver is unrelated to the more common bank beaver (*Castor*). It is the lone representative of a primitive family found only on the Pacific coast (Ingles 1965).

Damage from mountain beavers has been described by Lawrence et al. (1961). It includes stem clipping of small seedlings, branch cutting, and basal girdling. Lateral branches may be clipped from saplings up to a height of 10 ft (3 m) or more. The animals sometimes leave short branch stubs which may aid them in climbing (fig. 43). Bark is often stripped from trees, similar to damage by bears, but horizontal toothmarks and irregular claw marks distinguish this work from damage by bears. When small seedlings are clipped, the damage may be indistinguishable from damage by rabbits. In addition to damage in newly established stands, damage may occur after precommercial thinning (Waterman 1976).

Control of mountain beavers is difficult and expensive. A method of poisoning by use of toxic tracking foam has been developed (Martin 1969, Oita 1969), but restrictions on the use of poisons prohibit its use in many areas. Trapping is done in areas with dense populations and currently is the principal control method.

Porcupines damage trees by feeding on inner bark and foliage (fig. 44). They are not common in hemlock-spruce forests of Oregon and Washington. In Alaska they are found throughout the hemlock-spruce type, both on the mainland and on many offshore islands (Meehan 1974). Although porcupines damage both western hemlock and Sitka spruce, they have not been considered a serious pest in old-growth stands. As young, even-aged stands come under more intensive management they may become troublesome (Evans 1976). Little is known about numbers or extent of damage, although in very localized areas nearly every dominant tree may be damaged.[13/]

Figure 44.--Porcupines damage young hemlock and spruce trees in Alaska by girdling stems. This is not a problem in the Pacific Northwest.

Methods of controlling porcupines include hunting, trapping, and use of poison bait (Lawrence 1957). Porcupines' craving for salt allows the animals to be attracted to poison-bait stations; if used improperly, however, pesticides are capable of harming other forms of mammalian life (Hooven 1971).

Snowshoe hares (varying hares) damage seedlings within the hemlock-spruce type in Oregon and Washington (Canutt 1969, Lawrence et al. 19[illegible]),

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[13/] T. L. Thompson. Porcupine damage--Prince William Sound. Memorandum to Chugach National Forest, 10/16/73, on file at Forestry Sciences Laboratory, Juneau, Alaska.

primarily by clipping terminal shoots of seedlings up to 10 in (25 cm) tall. Trees clipped repeatedly are sometimes little more than small bushes. Leaders often escape beyond reach, however; and then damage is no longer a problem.

Snowshoe hares are present on the mainland of coastal Alaska and have been introduced on some islands. They damage or destroy Sitka spruce seedlings and young saplings.[14] Little is known about their population levels and the extent of damage caused, and no effort at control is being made in Alaska.

Various methods of reducing numbers of snowshoe hares with toxicants have not provided adequate protection for seedlings and have been hazardous to nontarget species. Two possible control methods are planting seedlings large enough to resist destruction and destroying habitat by land scarification (Hartwell 1969).

Brush rabbits damage seedlings in Oregon, but their range does ot extend northward into Washington (Canutt 1969).

In western Washington, black bears often damage young trees by stripping bark and girdling to reach the tasty cambium layer (Poelker nd Hartwell 1973) (fig. 45). Damage may occur from ground level to a height of 50 ft (15 m). Bears apparently prefer to work on thin bark (Childs and Worthington 1955, Levin 1954). Greatest damage has been reported on Douglas-fir; but western hemlock, western redcedar, and red alder are also attacked. Differences in chemical constituents within tree bark have been suspected in bears' preference for particular tree species, but chemical analysis alone has not been sufficient to explain feeding preference (Radwan 1969).

In southeast Alaska, brown bear sometimes damage Alaska-cedar trees by stripping bark. Such trees are not girdled and usually survive. The resulting catfaces are common on Alaska-cedar in some areas.

Figure 45.--Bear damage to Sitka spruce. Clallam County, Washington.

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[14] Tom L. Thompson. Reconnaissance report on natural reforestation of Woody Island clearing problems relating to varying hare and the implications to Afognak Island. Report dated May 24, 1974, on file, Forestry Sciences Laboratory, Juneau, Alaska.

Bank beaver cause minor damage to hemlock, spruce, and associat species throughout the type. Observations on the islands of British Columbia between Queen Charlotte Sound and Dixon Inlet show that beaver prefer western hemlock to alder for food (McCabe 1948).

In Alaska, beavers commonly cut young spruce, cottonwood, alder and hemlock for food and for construction of dams. Damage from tree cutting is restricted to the immediate vicinity of dams. More serio damage occurs from flooding caused by blocking of culverts. When flooding threatens to cause damage, beavers can be removed by trappi or by installation of fencing or "beaver bafflers" at the ends of culverts. The latter solution is often preferred because the presen of beavers can add to public enjoyment of recreation areas.

In addition to the animals mentioned, the red-breasted sapsucke (Ziller and Stirling 1961, Bent 1939), red squirrels (Meehan 1974), and probably many other creatures influence hemlock-spruce forests t some extent. As management intensifies, a thorough evaluation of wildlife damage throughout the range will be necessary.

In the past, efforts to reduce animal damage have emphasized direct control of wildlife by hunting, trapping, or poisoning. Thes direct methods too often have been unsuccessful or have caused serio side effects. More recently, emphasis on reducing damage by animals is shifting toward greater consideration of habitat management and less on direct control (Hermann 1969).

INSECTS

Most insect species in the hemlock-spruce forests feed on dead organic material. This hastens its breakdown and the release of nutrients for plant growth. Others are parasites or predators that help to regulate population levels of destructive insects. Insects provide food for fish, animals, and birds. Even insects that are destructive to individual trees may benefit the old-growth forest ecosystem through their influence on stand structure. Insects and their tree hosts have evolved together in the virgin forest ecosyste Insects become a problem when they compete with human activity.

As more old-growth stands are logged and forests converted to intensively managed, even-aged stands, the same level of insect dama may be unacceptable. Insects considered innocuous in virgin stands may then become serious pests (Silver 1962), and some form of suppression may be necessary (Mitchell 1970). Alternatives for pest management may include the use of chemicals, biological controls, an silvicultural practices designed to minimize the problems (Hard 1974

Most insect damage is caused by defoliators. In British Columb the most destructive defoliators have been the western hemlock loope the black-headed budworm, the saddle-backed looper, and the spruce budworm. Where Douglas-fir is present, it may be attacked by a numb of defoliators, beetles, and aphids (Mitchell 1970). A seedling wee has caused damage in Douglas-fir plantations and natural spruce regeneration (Lejeune 1962).

In coastal Alaska the black-headed budworm and the hemlock sawfly re, in order, the two most destructive forest insects (Hard 1967). estern hemlock is the preferred host of these defoliators, although itka spruce may also be attacked. Population levels appear to be elated to weather (Silver 1960, 1963; Schmiege 1966; Hard 1974a).

Outbreaks of the black-headed budworm and hemlock sawfly often ccur together. Frequently, a succession of outbreaks begins in the ympic Peninsula or southern British Columbia and progresses north to e Queen Charlotte Islands, southeast Alaska, and Prince William und. This northerly progression might be accounted for by the creasing time required for development toward the north associated th decreased temperatures during the growing season (Hard 1974b).

Other defoliators, as well as bark beetles, are present in coastal aska at endemic levels, occasionally undergoing population buildups d causing local damage. Relatively few insect species, however, are structive to the old-growth forests of southeast Alaska. Weather ring the growing season appears to be a major limiting factor in eir activity (Hard 1974a).

The spruce aphid, a sap-sucking insect, defoliates and kills Sitka ruce from California to Alaska. It is a serious pest of ornamental ees. The insect can reproduce throughout the year, so mild winters vor population increases. Epidemics are sporadic and short lived urniss and Carolin 1977). The insect has recently been active and causing considerable damage from Oregon to Alaska on trees near the en sea.

Hemlock and spruce residues rarely contribute to a buildup of sect populations that attack living trees. Forest residues harbor brosia beetles which readily attack felled and bucked timber and es felled by the wind or by other damaging agents. They cause tle or no damage to pulp timber but often seriously degrade saw s or veneer logs. Ambrosia beetles and other insects provide entry rts for disease organisms which, in turn, speed decay of residues tchell and Sartwell 1974).

In Alaska a localized outbreak of spruce beetle occurred in 1941 lasted several years. Origin of the infestation was thought to e begun in windthrown timber or in overmature live trees during an ormally dry period (Hard 1974b). Although it is possible for this ect to build up in logging slash, experience has not shown this to a serious problem.

The white pine weevil is the most serious enemy of young Sitka uce in Oregon, Washington, and British Columbia (Wright 1970, ver 1968) (fig. 46). It is not a problem on the Queen Charlotte ands or in southeast Alaska, where temperatures may be too low to low the insect to reproduce (McMullen 1976a, Gara et al. 1971). hin its range the white pine weevil is more damaging on drier sites ated inland away from the coastal fog belt (McMullen 1976b, Overhulser al. 1974). Before logging, many of these sites supported excellent -growth stands of spruce. These stands may have escaped weevil estation for one reason or another or may have survived numerous vil attacks during their early years. Given time then, such sites suitable for spruce. Under management, however, a merchantable

crop must be assured within a prescribed rotation. Delay caused by weevil infestation limits the suitability of these sites for future management of Sitka spruce. These sites are probably outside the practical range of Sitka spruce and, until weevil-resistant strains are developed, they should not be planted with spruce. In fact, under current management, weevil infestation is so severe in some areas along the Oregon and Washington coast that Sitka spruce is no longer planted.

Figure 46.--Weevil damage to Sitka spruc Photo taken in May showing the dead to of a tree that had been attacked a yea earlier. Clatsop County, Oregon.

Research is underway to find or develop weevil-resistant varieties or strains of Sitka spruce. In Oregon, a 15-year test of susceptibility to weevils showed that Lutz spruce, a naturally occurring hybrid between Sitka and white spruce on the Kenai Peninsula, Alaska (Little 1953b), was the most promising replacement (Mitchell et al. 1974).

A survey of insect activity is conducted annually in Oregon, Washington, and Alaska by the USDA Forest Service. Results of the surveys are published yearly by the U.S. Department of Agriculture in a series titled, "Forest Insect and Disease Conditions in the United States A similar survey is carried out annually in British Columbia by th Canadian Forestry Service, with annual reports by district publish by the Pacific Forest Research Centre, Victoria, B.C. Over the ye these reports are adding substantially to our knowledge of insect activities. In addition, there is a need to quantify the damage caused by insects, to evaluate the relative importance of insect problems within the hemlock-spruce type, and to establish costs an benefits of various alternative methods of controlling insects.

FLUTING

Fluting, or the presence of deep vertical grooves in the main stem of western hemlock, is a problem in Alaska (Harris and Farr 1! The extent of area affected within the hemlock-spruce type is not known, but severity decreases southward. We have noted occasional hemlock with slight fluting as far south as Vancouver Island. Fluting is rare in Washington and Oregon. Fluting is particularly

noticeable in some even-aged stands (fig. 47); the agent or mechanism that triggers its development is not known.

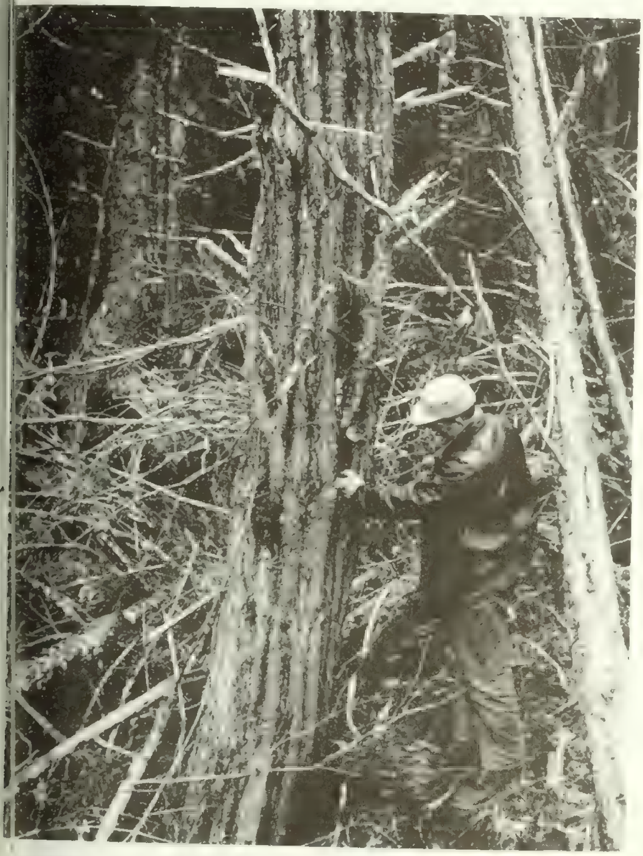


Figure 47.--A badly fluted western hemlock in an even-aged stand, Prince of Wales Island, Alaska. Fluting decreases pulp yield and can make trees unsuitable for sawtimber. Sitka spruce is not affected.

In southeast Alaska, seriously fluted stands occur over the range of sites. Some second-growth stands are so badly affected that the hemlock component is of no merchantable value for sawtimber (Alaska Forest Research Center 1957, p. 24-25). Ingrown bark can be separated from the wood in pulping, but the process is more costly, and there is less cubic-foot volume in fluted logs. Spruce apparently is not affected. A fluting problem affecting Sitka spruce has received attention in Britain (Day 1958, 1964). Day (1964) suggested that development of flutes may be due to problems of water transport and supply within the stem, as influenced by the condition of the root system and the demand made by the crown.

Intensive management of second-growth stands in Alaska could be influenced by knowledge of the cause of fluting of hemlock. Soil, stand density, root disease, frost, or genetics might be responsible. A detailed study of the problem is needed.

FOREST DISEASES

Both biotic and abiotic agents contribute to forest diseases. In hemlock-spruce forests the most important biotic agents are dwarf mistletoe, a parasitic plant, and the fungi that cause wood decay, needle cast, cankers, death of shoots, and wood staining. Abiotic agents include heat, freezing, drought, flooding, mechanical damage, and air pollution. Often there is an interaction--for example, drought-stressed trees may be more succeptible to pathogens; wind-broken tops serve as entry courts for decay fungi. An excellent source of information on diseases of forest trees is available (Hepting 1971).

Most organisms that cause disease are endemic in hemlock-spruce forests, and many are beneficial. Wood-destroying fungi are essential for breaking down and recycling nutrients contained in the stems, limbs, and foliage of fallen trees.

Although some of the slash-inhabiting fungi also attack living trees, their presence in logging residues does not greatly increase

the risk of infecting the residual stand. Inoculum is already pre
from other sources in the forest, and rate of infection is governe
mostly by occurrence of entry courts in living trees rather than
absence of inoculum (Childs 1939, Aho 1974). Fungi that cause roo
rots--such as *Fomes annosus*, *Phellinus* (*Poria*) *weirii*, and *Armilla*
mellea--however, survive as saprophytes in stumps and roots after
tree is harvested and may spread through root contact to residual
trees (Nelson and Harvey 1974).

Loss of productivity from disease may be almost unnoticed. T
loss is not spectacular as with insect epidemics, blowdown, or fir
Fire may be the most spectacular; yet over a rotation, disease may
cause far greater loss of timber--perhaps more than from any other
damaging agent. Decay, caused by heart- and root-rotting fungi,
is probably the greatest single cause of loss of volume in the for
of southeast Alaska (Laurent 1974).

Losses from decay fungi in Alaska are high, principally becau
of the old-growth structure of the forests (fig. 48). About 31 pe
of the gross board-foot volume in old-growth stands is estimated t
unusable as sawtimber.[15] Conifers up to 100 years old have littl
decay. Thereafter, the probability of a tree having rot increases
rapidly. By 200 years, 65 percent of the cedar, 50 percent of the
hemlock, and 20 percent of the spruce contain some rot (Kimmey 195

Defect varies greatly within and between tree species. For example, in Alaska, defect in old-growth Sitka spruce averages about 9 percent of total gross volume; in western hemlock, about 22 percent; and in the cedars, about 52 percent (Hutchison 1967).

In Oregon and Washington, Englerth (1942) found that in western hemlock the four most important decay organisms were: *Fomes annosus*, causing 21 percent of the board-foot decay; *F. pini*, 19 percent; *F. applanatus*, 17 percent; and *F. robustus*, 10 percent.

In the Queen Charlotte Islands, total loss from decay of western hemlock was 25 percent of the gross volume (Foster and Foster 1951). Most losses were in older and larger trees; no single fungus caused loss of more than 2 percent of gross volume.

In Alaska the brown rots account for 84 percent of the decay

Figure 48.--Diseases of the tree
caused by fungi are common in Al
Conks on this old-growth western
lock near Juneau indicate that t
tree contains extensive rot.

[15] Forest Survey Statistics on file, Forestry Sciences Laboratory, Junea
Alaska.

Sitka spruce. The white rots account for 68 percent of the decay western hemlock and 98 percent in western redcedar. *Fomes pinicola*, brown rot fungus, causes 74 percent of the decay in Sitka spruce and percent in western hemlock. In western hemlock, the white rot ngi *Armillaria mellea* and *Fomes annosus* account for 20 and 22 percent the decay. The white rot fungi *Poria albipellucida* and *Phellinus oria) weirii* account for 46 and 41 percent of the decay in western dcedar (Kimmey 1956).

In old-growth stands, little can be done to reduce defect or sease. Cutting priorities, however, first should be to remove the st decadent stands occupying productive sites. Conversion from old owth to vigorous young growth has great potential for reducing decay. ot rot problems, however, are becoming more apparent in young growth. y reduce growth and vigor and are important in management of young-owth stands.

Infection by *Fomes annosus* from old stumps to new seedlings can ad to serious damage in hemlock plantations. A study in western ashington showed the presence of some infection before thinning in stern hemlock stands 20 to 60 years of age. After thinning, a atively high rate of stump infection (50-90 percent) was found, icating a high potential for stand infection during the remainder the rotation (Driver and Wood 1968). This pathogen destroys lignin the wood, but cellulose is largely unaffected. The base of the st log may be destroyed for lumber recovery but still be usable for p. Treatment of stumps with chemicals immediately after cutting help to prevent infection (see page 73). The thin bark and llow roots of hemlock and spruce make them particularly susceptible logging injury. Bark and root scarring can lead to serious decay, ecially in hemlock (Buckland et al. 1949; Foster and Foster 1951; ght and Isaac 1956; Shea 1960, 1961; Wallis et al. 1971).

In the late 1960's a stem disease, identified as *Sirococcus obilinus* (Funk 1972) (fig. 49), was first noted in stands of young-wth hemlock in Alaska. The disease causes dieback of the tip and eral branches and kills some trees. The potential for damage is known, but one survey suggests that damage to managed stands is ght (Wicker et al. 1978). Research is needed to evaluate the anism in Alaska.

Air pollution may damage forests in localized areas. In Alaska, ur oxide emissions from two pulpmills have injured and killed a spruce, western hemlock, western redcedar, and Alaska-cedar. In case trees on approximately 400 acres (160 ha) were killed rent 1974).

Hemlock dwarf mistletoe is an important disease of western hem- (Baranyay and Smith 1972, Childs and Shea 1967, Russell 1976, and Stewart 1972). Mistletoe can best be controlled as mature ds are harvested. Silvicultural practices designed to control f mistletoe can be included in management plans, often at little tional cost, as discussed in the following section.

Dwarf Mistletoe Control

Figure 49.--A stem dieback of western hemlock caused by Sirococcus strobilinus *is common in some young hemlock-spruce stands in southeast Alaska.*

Western hemlock is susceptible to infection by hemlock dwarf mistletoe throughout the Sitka spruce-western hemlock type as far north as Haines, Alaska (Hawksworth and Wiens 1972). Infections usually occur in a patchlike distribution, apparently correlated with stand history. Annual loss of growth and reduction in wood quality are not accurately known, but hemlock dwarf mistletoe certainly is a factor affecting financial returns from coastal old-growth forests. It disrupts the normal development of the tree by causing stem swellings, gall-like growths that weaken the stem, brooming of branches, and variations in wood density. It provides entry points for decay organisms through broken stubs or old brooms and patches of dead tissue over infected areas. Rate of height growth is reduced and then diameter growth as the intensity of infection increases. In dense stands, infected trees tend to be overtopped and die; in open stands they remain to become severely deformed (fig. 50). Many trees are killed outright by severe mistleto infection. Others are weakened and later succumb to decay organisms, insect attack, or wind.

Dwarf mistletoe can be controlled by silvicultural treatment, and often this should be the first step in bringing a stand under intensiv management.

There is a large body of literature on dwarf mistletoes; most of it is on the pines, but control recommendations are generally applicab to hemlock. In recent years more emphasis has been on hemlock. The literature was reviewed by Gill (1935), Kuijt (1955), Gill and Hawkswo (1961), and Hawksworth and Wiens (1972). Recommendations for control were prepared by Graham (1967), Russell (1976), and Baranyay and Smith (1972). Research specifically on hemlock dwarf mistletoe has been reported by Buckland and Marples (1952), Shea (1966), Smith (1964 1966, 1968, 1969, 1971, 1973, 1977), and Wellwood (1956). The followi background information and examples of control procedure are mainly ba on these reports.

Figure 50.--Dwarf mistletoe on western hemlock, southeast Alaska.

Within the hemlock-spruce type, western hemlock is the principal ost of hemlock dwarf mistletoe (Russell 1976). Sitka spruce is ssentially free of the disease, with only a few reports of infection--hichagof Island, Alaska (Laurent 1966), Kitimat, British Columbia Molnar et al. 1968), and southern Vancouver Island.[16] Infection of emlock dwarf mistletoe has been collected on mountain hemlock in ritish Columbia (Ross et al. 1973). Infection has been reported in laska (Weir 1915) but has not been substantiated by recent collections.[17] econdary hosts include shore pine, Pacific silver fir, subalpine fir, nd white pine. Douglas-fir and western redcedar are resistant to the isease (Baranyay and Smith 1972).

16/ Personal communication from R. B. Smith, Canadian Forestry Service, Pacific orest Research Centre, Victoria, B. C., 1977.

17/ Personal communication from Thomas L. Laurent, USDA Forest Service, Juneau, laska, 1978.

Background Information

Dwarf mistletoes are flowering, seed-bearing plants with endophy systems or "roots" that invade woody tissues of host trees. Dwarf mistletoes produce a fruit with an explosive seed-dispersal system that can expel seed at initial velocities well over 50 ft (15 m) per second. As the berry matures, its stem is recurved so the top of the berry points downward; viscin cells between the seed and the berry's hull absorb water, creating a high internal pressure. When the frui drops from the stem, the hull rapidly contracts, ejecting the seed upward and outward. Seeds are coated with a mucilaginous substance (viscin), enabling them to adhere to the surface of the host. Disper distance ranges up to 50 ft (15 m), but most seeds land within 30 ft (9 m) of the source plant (Smith 1973). Dispersal can be increased somewhat by storm winds and steep slopes.

Some seeds land on susceptible twigs; but because of the much greater target area, most are intercepted by needles. These must mov to susceptible woody tissue by gravity, washing by rain, or other means to cause infection. A study on Vancouver Island showed that of seed dispersed from mistletoe in an infected residual tree, 37 percen attached firmly to nearby hemlock seedlings and 13 percent caused infection (Smith 1977).

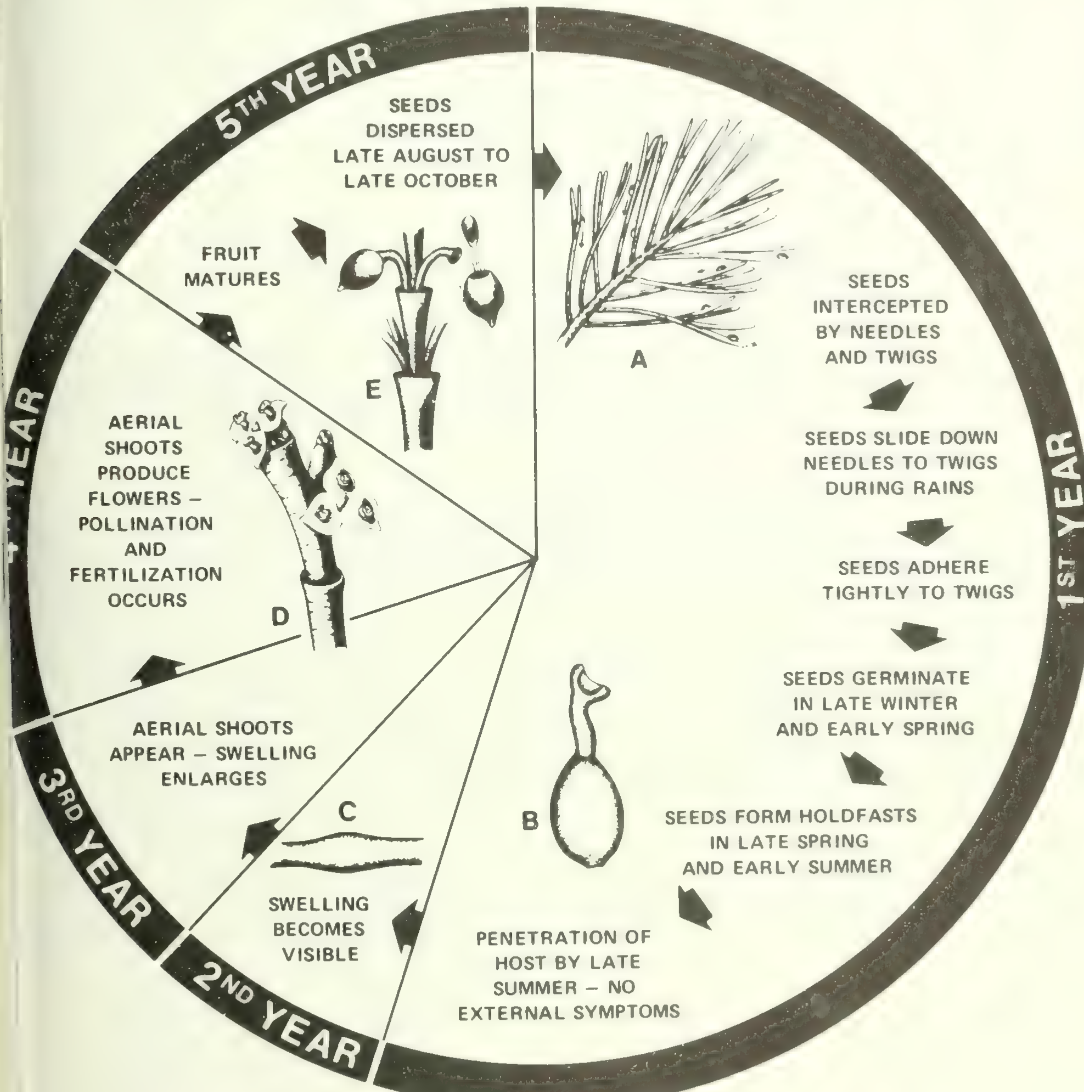
The ecology of dwarf mistletoe seed is well documented (Wicker 1974). Seed germinates in late winter or early spring, a mound of tissue or "holdfast" is formed, usually at the base of a needle, and infection of the host is initiated by means of a penetrating structur developing from the holdfast. This ends the brief self-sustaining phase of the dwarf mistletoe plant; thereafter, it is largely parasiti

Growth of the endophytic system and associated hypertrophy of host tissue forms a characteristic fusiform or spindle-shaped swellin which is the first outward sign of infection (fig. 51). Aerial shoot

Figure 51.--Spindle-shaped swelling of branches is usually the first sign of hemlock dwarf mistletoe infection.

re produced 2 or more years after penetration. Shoots range up to in (13 cm) long and have rudimentary green leaves appearing as small cales at the internodes and lending a segmented appearance to the hoot.

Flowers develop in late summer and are pollinated mainly by nsects. Fruit matures in the fall of the succeeding year. Dwarf istletoe is dioecious, with male and female plants located at different nfection points. Total life cycle, or the period from infection by eed to production of seed, is from 4 to 8 years (fig. 52)--an important oint to consider when planning control measures.



Generalized life cycle of dwarf mistletoe
A. Needle angles as they affect dwarf mistletoe seed movement.
B. A fully developed dwarf mistletoe seedling with holdfast.
C. Small branch swelling is the first indication of dwarf mistletoe infection.
D. Male (staminate) flowers of dwarf mistletoe.
E. Dwarf mistletoe seed discharge.

gure 52.--(Reproduced from Baranyay and Smith 1972, fig. 7; with permission.)

Spread is always greater in open than in dense stands where nearby foliage intercepts seed. The most rapid spread is from an overstory to the understory below. After logging, seed can spread from 30 to 50 ft (9-15 m) the 1st year seeds are produced. A single infected overstory tree disperses seed over an area of nearly 6,000 ft^2 (560 m^2) (Smith 1966). Thus, if trees are evenly distributed, less than 10 infected trees per acre (25/ha) could infect all intervening hemlock regeneration (Baranyay and Smith 1972). With early removal of the overstory seed source, about 86 evenly spaced, severely infected residual hemlock per acre (212/ha) would be required to produce a level of infection sufficiently high to cause significant early damage on all intervening hemlock regeneration (Smith 1977).

The lateral rate of spread through even-aged stands of hemlock is not known. Spread in even-aged pine has been estimated at generally less than 2 ft (0.6 m) per year; spread through open stands is about 1.5 times faster than through closed stands because mistletoe plants are more vigorous and seed travels farther (Hawksworth 1958).

Long distance spread of dwarf mistletoe is less common. It is usually attributed to birds who remove the sticky seed from their feathers while preening.

The upward advance (vertical intensification) of infection in the crown of a tree proceeds at the rate of about 2 ft (0.6 m) per year, the rate being more rapid in open than closed stands (Richardson and van der Kamp 1972).

There is the possibility that vigorous trees will outgrow dwarf mistletoe. Russell (1976) suggests that the vigor of dwarf mistletoe is correlated with the vigor of the host. Thinning, therefore, increase dwarf mistletoe growth; but it also stimulates tree growth, and the net effect is uncertain.

Dwarf mistletoe infection centers usually occur in a patchlike pattern related to the origin and development of the stand. They tend to be well defined, with narrow transition zones from infected to uninfected stands. Wildfire or broadcast burning of logging slash destroys most of the dwarf mistletoe seed source, and a new crop of hemlock seedlings can develop into an even-aged stand essentially free of the disease. On the other hand, young stands that become established prior to removal of an infected overstory may develop severe infection. The most severe infections seem to be in all-aged stands, where young trees are periodically showered with seeds from the overstory as they develop.

Few surveys of mistletoe infection have been made in coastal forests, and the nature and extent of infection is not well known. Shea (1966) reported that pockets of infection occur along the Columbia and Quinault Rivers on the Washington coast, and infection was more severe near the ocean. Greatest infection was in all-aged stands or those that had developed under an infected overstory. Similar results were obtained in the Waldport, Oregon, area of the Siuslaw National Forest. Infection was most intense along moist creek bottoms, presumably because past wildfire had skipped over wet areas, leaving infected trees as a mistletoe seed source.

Infected hemlock trees advance through stages of initial infection, brooming, stem swelling, development of spiked tops, and ultimate decline. Shea (1966) found that in 60- to 80-year-old well-stocked stands diameter increment did not suffer unless infections were severe and deforming. Smith (1964) classified trees by intensity of infection as light, medium, and heavy and for each class compared height growth during the decade 1950-60 with growth during 1920-30. Reduction in growth attributed to intensity of infection was 9, 19, and 57 percent, respectively.

Shea observed that severely infected trees were often overtopped by their neighbors. This was documented later by Smith (1968) who felled and sectioned lightly and severely infected trees that averaged 110 years old. The severely infected trees proved to be 39 years older, and in 1905 averaged 17 ft (5 m) taller than the lightly infected trees. By 1960 the lightly infected group was growing 90 percent faster in height and 34 percent faster in volume. When felled and sectioned in 1963, the lightly infected trees had surpassed the others, indicating the start of a selection process favoring lightly infected trees.

Growth losses in dense stands are reduced when adjacent mistletoe-free or lightly infected trees are available to replace those severely infected. Also under dense canopies, brooms often die or remain small. The net effect on growth in dense stands may be small and overshadowed by the competitive effects of severe overstocking. In open stands and along stand borders, dwarf mistletoe spreads faster, and trees are deformed earlier and more severely.

Englerth (1942) first documented that dwarf mistletoe infection leads to damage by other agents. He dissected 801 western hemlock trees, mostly on site 3 and 4 lands in western Oregon and Washington. He found that dwarf mistletoe burls and swollen limbs near the trunk had provided the entry courts for over 30 percent of the decay volume. The principal decay organisms gaining entrance this way were white mottled rot (*Fomes applanatus*), white trunk rot (*F. hartigii*), and white spongy rot (*Ganoderma oregonense*). Western hemlock trees weakened by dwarf mistletoe infection are more vulnerable to insect attack. For example, infected trees do not survive successive defoliations by the hemlock looper as well as dwarf mistletoe-free trees (Buckland and Marples 1952).

Dwarf mistletoe infections also affect wood properties. A beneficial effect is that reduced specific gravity and lower moisture content of infected wood improves floatability of hemlock logs. Most other effects are detrimental. Harvesting deformed trees with broomed limbs and spiked tops is dangerous. The hard, dense knots associated with broomed limbs dull saws and chippers. Variations in specific gravity in infected logs cause warping of lumber, and the lowered specific gravity suggests lower strength properties and pulp yield (Wellwood 1956).

Techniques For Control

The outlook for dwarf mistletoe control is good. It can be controlled silviculturally by cutting infected trees, thereby removing the seed source, or by establishing nonsusceptible species, such as Sitka spruce, Douglas-fir, or cedars.

The possibility of using biological agents for control of dwarf mistletoe has been investigated. Three species of fungi that restri development of aerial shoots have been found; other fungi, birds, rodents, and insects are being studied (Hawksworth and Wiens 1972). Biological agents, however, have not yet proved successful for opera tional control (Russell 1976).

Considerable work has also been done on the development of chem to control dwarf mistletoe, but no material has been found that warr widespread application (Baranyay and Smith 1972).

A detection survey is the basic step in a control program, the objective being to determine occurrence, distribution, and intensity of infections and to identify areas where intensive surveys are need The survey often can be conducted concurrently with timber cruising, presale planning, or sale layout (Shea and Orr 1963, Graham 1967). Boundaries of infected areas often coincide fairly well with timber type boundaries, and to this extent aerial photos would be useful in mapping them.

Dwarf mistletoe infections occur in a patchwise and nonrandom pattern, and an operational survey is usually needed to delineate infection boundaries and to assemble facts for deciding for or again treatment and the best type of treatment. Information needed includ

1. Age of stand and current cutting plans.

2. Species composition and suitability of site for species ot than hemlock.

3. Intensity of infection in the understory, density of stock and crown characteristics.[18]

4. Topography and available logging methods and their effects the minimum area that can be treated economically.

5. Available residue disposal methods.

6. Restrictions due to recreation use, esthetic values, etc.

The second step in a control program is to select the best trea ment for each stand condition. Two general approaches are available removal of the seed source by cutting infected trees and substitutio of a nonsusceptible species. Basic steps to be taken in the first approach include removal of all infected overstory, sanitation cuttings in the understory, and followup sanitation treatments as requi If severely infected, the entire understory should be destroyed. Th second approach, substitution of a nonsusceptible species, can be do by seeding, planting, or favoring a nonsusceptible species in precommercial and commercial thinning. The following examples and discussion illustrate some conditions found, factors considered, and treatments applied.

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[18] The six-class rating system developed by Hawksworth (1977) (fig. 53) provides a method for describing intensity of infection. A modification of the system may prove desirable in dense hemlock stands (Smith 1969).

A condition often found in Alaska and British Columbia is infected ld-growth hemlock in mixture with Sitka spruce, with an understory of lmost pure hemlock of various sizes severely infected by a periodic arrage of mistletoe seed. The prescription is to clearcut the stand nd destroy infected understory seedlings and saplings by logging. nfected saplings not destroyed during logging are cut later by a pecial crew. The objectives are to stop deterioration of the decadent ld growth and eliminate the dwarf mistletoe seed source; then the new tand, whether established by natural regeneration, seeding, or planting, an develop free of infection.

Variation in tree height and density of stocking in a young stand re important factors determining response to dwarf mistletoe infection. nfected trees growing in the open or extending above the general anopy may develop vigorous infections, produce lots of mistletoe eed, and infect surrounding trees that may have escaped earlier nfection.

Large variations in density of stocking and in tree height usually re found in the understory of mistletoe-infected, old-growth stands; o control action by clearcutting is usually indicated.

When a young stand has light infection or infection centers are idely distributed, sanitation cuttings are indicated. The objective s to remove as many infected trees as economically feasible, particularly hose above the general canopy in a position to shower mistletoe seed o nearby trees.

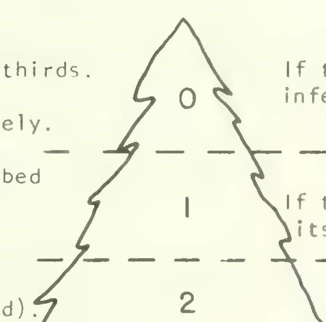
Most sanitation cutting should be done in conjunction with juvenile pacing or early precommercial thinning operations. The optimum time eems to correspond well for both spacing and sanitation; that is, etween a stand age of 10 and 20 years. Only healthy hemlock should e selected for crop trees. When hemlock crop trees are selected, the six-class rating system of Hawksworth (1977) may be a useful guide (fig. 53). For example, at stand age 20 the objective might be to leave no

INSTRUCTIONS

TEP 1. Divide live crown into thirds.

TEP 2. Rate each third separately. Each third should be given a rating of 0, 1 or 2 as described below.
(0) No visible infections.
(1) Light infection (1/2 or less of total number of branches in the third infected).
(2) Heavy infection (more than 1/2 of total number of branches in the third infected).

TEP 3. Finally, add ratings of thirds to obtain rating for total tree.



EXAMPLE

If this third has no visible infections, its rating is (0).

If this third is lightly infected, its rating is (1).

If this third is heavily infected, its rating is (2).

The tree in this example will receive a rating of 0 + 1 + 2 = 3.

Figure 53.--The six-class mistletoe rating system (Hawksworth 1977).

hemlock trees with a rating of more than 2; at stand age 10 no hemlock with a rating of over 1. In this way the most heavily infected trees are removed; those left are not likely to sustain significant losses o can be removed in later intermediate cuttings if they have become more seriously infected.[19/] Additional selection can be on the basis of resistant species, such as Douglas-fir or Sitka spruce. If crop trees are selected on the basis of diameter, there will usually be a tendency to select these resistant species because their diameters are usually larger than hemlocks' at this age class.

Control by manipulation of species can be accomplished by clear-cutting and planting desired species. Seeding usually is not appropri because hemlock may seed in naturally and dominate the site. Broadcas burning, if practiced in the area, will help destroy infected hemlock seedlings and clean up the area for more efficient planting.

In recreation and special use areas where it is desirable to maintain a forest canopy and timber production is not the major objective, control of dwarf mistletoe may not be warranted. In fact, the bizzare shapes of trees with severe stem infections and branch broomin may add to the esthetic appeal of some stands. In campgrounds and other heavily used areas, however, the heavy brooms may be hazardous. Current recommendations call for pruning of heavy, broomed branches in the interest of safety. Stem infections can also contribute to stem breakage during windstorms, and this factor should be considered in selection and maintenance of recreation areas.

Timber along cutting lines, if infected, can be a source of infection for adjacent reproduction for about 50 ft (15 m) from the line, depending on slope. This edge effect becomes more important as the size of the regenerated area decreases, because small areas have a proportionally larger perimeter. The edge effect can be minimi by locating cutting lines through mistletoe-free areas or by using clearings, rock outcrops, lakes, streams, roads, or meadows as cutting boundaries. Spread of infection can also be reduced by thinning infected trees from adjacent timber, by destroying hemlock and plantin a resistant species in a 50-ft (15 m) strip around the edge of the regenerated area, or by cutting the adjacent stand while the hemlock reproduction is from 5 to 10 years of age or still small enough that only a few seedlings have had time to be infected.

Every stand is different, and the above examples illustrate some of the situations found. A separate control plan should be developed for each infected area. The general objective is to minimize losses in forest value commensurate with realistic costs of control

Dwarf mistletoe control programs need not always compete with silvicultural treatments needed for other purposes, because in many cases they can be combined. Priority for control measures should be set on the basis of cost and feasibility of control and probable benefits. Often these will be prevention measures in newly regenerate stands; for example, removal of infected saplings during or after logging. Removal should not be delayed long as infection from residua trees increases with age of the stand (Stewart 1976). Felling or herbicide treatment costs are low, and future productivity of the new stand may be increased considerably. In an active mistletoe-control program, infected saplings should be cut during the logging operation, thereby avoiding a special trip over the area. Sanitation thinning in

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[19/] Personal communication, R. B. Smith, Canadian Forestry Service, Pacific Forest Research Centre, Victoria, B.C.

onnection with early spacing operations in young stands often comes ext, followed by salvage of dwarf mistletoe-infected, mature or vermature trees.

The last step in a control program is to schedule followup treatments t approximately 5-year intervals after initial treatment. Infections issed earlier should be recognizable but should not have had time to isseminate much seed.

Hemlock dwarf mistletoe is a forest disease that can be truly ontrolled through silvicultural treatment, often at little additional ost. Successful control will require intensive management in the orm of thorough planning, careful treatments, and systematic followup.

Detailed benefit-cost analyses for control of hemlock dwarf istletoe are not possible at this time. Although it may be possible determine growth reductions in individual trees, growth losses annot be determined on a stand basis. Yield tables now in common sage cannot be used for bench-mark purposes because it cannot be nown if sample trees were infected and if so, to what intensity.

Benefits of a control program in recreation and special use areas nnot be evaluated only in terms of growth losses but must be evaluated so in terms of safety and risk. Benefits may be analyzed from an tuarial or legal standpoint more effectively than from a strict onomic standpoint.

Certainly, more information is needed on silvicultural control, duction in stand yield, parasite-host relationships, and the possiblities of chemical, biological, and genetic control. Current control ograms, however, should not be delayed for new information.

NIMIZING WIND DAMAGE

Wind damage is common in the hemlock-spruce type. Each year storm winds take their toll in uprooted and broken trees, reduced gowth rate from broken branches, and the shearing of twigs and laves. Occasionally, storm winds cause spectacular losses. Five etensive blowdowns occurred:

Date of storm	Area covered	Volume of blowdown (Million fbm)	Reference
Jan. 9, 1880	Northern Oregon and southern Washington	--	Decker et al. 1962
Jan. 29, 1921	Olympic Peninsula	[20] 8,000	Decker et al. 1962
Dec. 4, 1951	Western Oregon	[20] 3,700	Ruth and Yoder 1953
Oct. 12, 1962	Western Oregon and western Washington	[20] 11,190	Orr 1963
Nov. 1968	Southeastern Alaska	5,000	[21]

[20] Volumes shown include damage inland.
[21] Unpublished data on file, Region 10, Timber Management, Juneau, Alaska.

Scattered blowdown also occurs during years when there is no catastrophic storm and often goes unnoticed except by local land managers. This storm damage also adds up to large losses. In overmature stands, trees may be weakened by root or stem rot or dwarf mistletoe infection and may blow down, even though the windstorm is not particularly severe.

Storm damage also may be classified as uprooting, stem breakage, crown damage, and root damage. Uprooting occurs mainly on poorly drained soils and stem breakage on well-drained soils. It is important to differentiate between these situations because trees growing on them need to be treated differently.

Wind damage to needles, twigs, and branches is less spectacular but is important. After a major storm the forest floor may be carpeted with a layer of this material. Productivity of the forest is slowed while the photosynthetic area is being replaced.

Root damage occurs when roots work up and down in the soil during wind sway; this too slows growth. Trees are less windfirm during the recovery period. Root damage also provides an entry court for disease organisms.

Sudden exposure of trees along blowdown edges also causes growth reductions. There is a slowing of height growth and sometimes dieback of tops. Spruce tends to put out epicormic branches along the stem, resulting in a lengthening of the crown and a lowering of the center of gravity of the tree.

Risk of wind damage varies widely, depending on exposure to storm winds. In severely exposed localities, forest management must be dictated largely by wind. The forest manager should recognize the risk and design the silvicultural systems to minimize wind damage. Barring catastrophe, the manager should be able to carry out harvest cuttings, regeneration, and stand management with little disruption—even though wind dictated the planning. On the other hand, the manager may design the silvicultural systems with little concern for the wind, only to have to alter plans time after time. The result will be mainly a salvage operation dictated by the wind.

Even when downed trees are salvaged, there is substantial financial loss. There is investment loss from premature harvest of the trees, broken trees with volume loss, and downgrade caused by insect attack and decay. Downed timber must be salvaged promptly because of rapid deterioration (Boyce 1929, Childs and Clark 1953, Shea and Johnson 1962). There may be damage to improvements such as roads, culverts, fences, and buildings. There may be premature replanting costs. Logging costs are higher, and hazards are increased. The logger has no choice in direction of fall and must often work slowly to insure safety. A catastrophic storm can disrupt markets through an oversupply of logs and consequent drop in price. The supply can exceed the local manufacturing capacity, and this will require that logs be transported out of the local area.

Details of wind behavior in coastal forests and recommendations for reducing wind losses follow.

The North Pacific Wind System

Most winter storms originate in the western Pacific and follow a course east and northeast across the North Pacific to the west coast of North America. These cyclonic storms rotate counterclockwise around a central area of low barometric pressure. The prevailing storm tracks, as well as areas of maximum occurrence and genesis, are generally farthest south in February, farthest north in August, and farther south in spring than in fall (fig. 54) (Klein 1957). The normal storm track along the Aleutian Chain, the Alaska Peninsula, and the Gulf of Alaska exposes these areas to a majority of the storms crossing the North Pacific (Searby 1968). On an overall basis, the Gulf of Alaska leads the northern hemisphere every month from October through May in cyclonic frequency (Klein 1957).

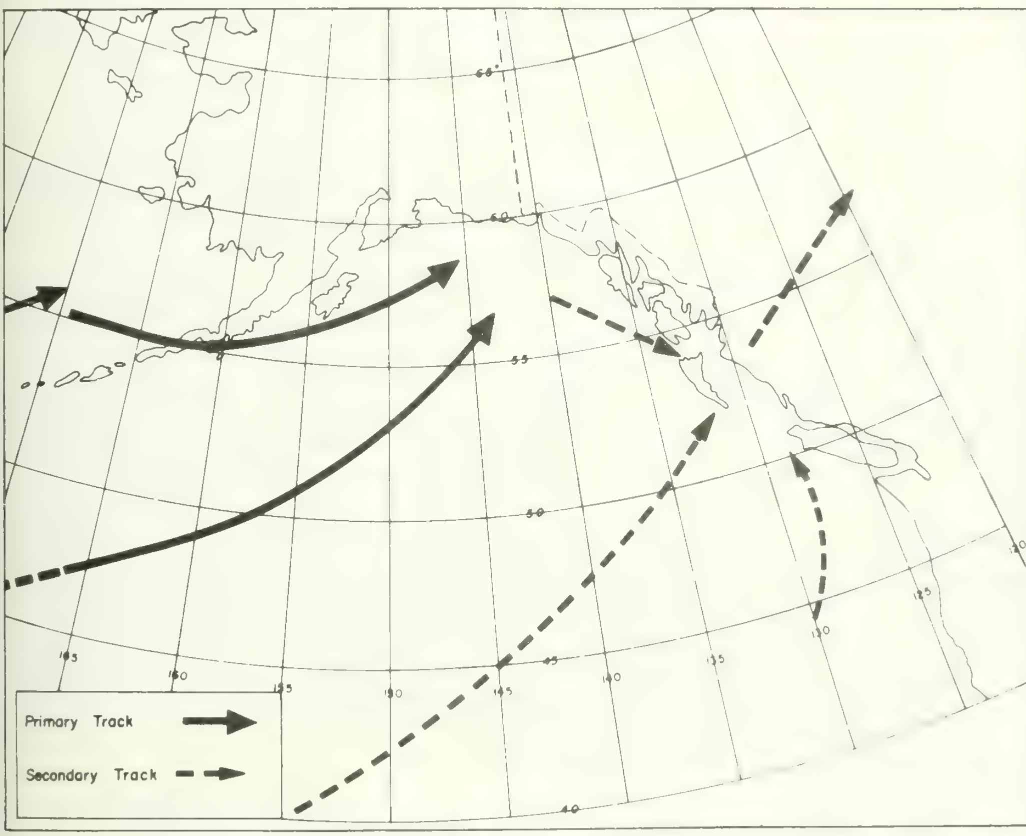

Figure 54.--Principal tracks of low-pressure areas across the North Pacific Ocean for November (Klein 1957).

In Oregon and Washington, the highest velocity and greatest damage has been from south and southwest winds of an approaching storm. Gale-force winds approach the shoreline with increasing frequency in October and November, reach a peak in December and January, then decrease in February and March (U.S. Navy Hydrographic Office 196 .

In southeast Alaska, the strongest and most damaging winds are from the southeast; they occur in the fall, particularly during Septem r October, and November (Searby 1968). The storms that produce these winds frequently begin as wave developments on cold fronts or occlusic that have passed east of the coastal range and trail into the gulf near the stationary weather ship located at 50°N, 145°W. The wave develops to the east or southeast of this and remains rather weak and fast-moving until it approaches the coast in the vicinity of the Queen Charlotte Islands. At this stage, it deepens rapidly and moves north-northeastward at 40 to 50 mi/h (64 to 80 km/h), often accompanied by winds of gale force. Most often the time interval, from the time the wave is detected until it has moved through the entire Alaska panhandl is only 24 to 30 hours. This type of storm produces wind gusts that at times exceed 100 mi/h (160 km/h) in southeast Alaska and 80 mi/h (130 km/h) in the northern sections.22/

Two examples of damaging gales are the Columbus Day storm of October 12, 1962, which battered Oregon and Washington forests, and the Thanksgiving Day storm of November 28, 1968, which raked southeast Alaska.

The Columbus Day storm of 1962 (Decker et al. 1962, Lynott and Cramer 1966, Orr 1963) followed a variable path across the Pacific, finally reaching a deep low of 960 mbar near latitude 40°N and longitude 130°W off the coast of northern California about 10 a.m. P.s.t. This was far southeastward from the usual location of deep lows. The Columbus Day low then followed a northward course just off the coast and reached the mainland at Tatoosh Island, Washington, some 12 hours later. Most anemometers were destroyed by the wind, but windspeeds, based on geostrophic winds as indicated by differences in barometric pressure, were estimated by Lynott and Cramer (1966). Maximum 1-min velocities of surface winds estimated as 50 percent of geostrophic winds were 100 knots/h (185 km/h) in Oregon and Washington coastal areas. Orr (1963) reported maximum gusts at 117 knots/h (217 km/h). General wind direction was southerly. The storm winds traveled northward along the coast with no major mountain ranges in their path. The intensity of the low did not subside until the storm angled inland in northern Washington and British Columbia.

The severe storm that produced extensive damage throughout southea Alaska on Thanksgiving Day of 1968 was an especially severe example of a fall gale. As the storm approached the Alaska panhandle, the pressure fell rapidly at Annette Island for a prolonged period of time, reaching a low of 736 mbar. Once the frontal system passed Annette Island, barometric pressure there began rising rapidly while the pressure at Sitka and Juneau continued to fall rapidly. A low pressure of 725 mbar was recorded at Juneau prior to frontal passage. The Thanksgiving storm produced windspeeds to 50 mi/h (80 km/h, with

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22/ Personal communication from Lief Lie, Weather Service Forecast Office, NOAA, Juneau, Alaska.

usts as strong as 90 mi/h (145 km/h) in the Ketchikan area and gusts o 78 mi/h (126 km/h) in Juneau (see footnote 22).

ora Winds

During the winter months, cold, dry winds occur in many places long the Pacific coast. These fall or bora winds develop where steep ountain ranges parallel the coast, producing sharp climatic differences etween the cold interior and warmer coastal areas. Winds of this ype are common in coastal mountainous areas throughout the world nd are usually known by local names. In Europe the bora (derived rom the Greek boreas, "north wind") which occurs along the coast of almatia on the Adriatic Sea is the best-known example and serves to dentify the type. Examples from southeast Alaska are the Taku winds n the Juneau area and the Stikine wind in the Wrangell area (both amed for local river valleys). Farther south, the strong winds that ccasionally blow out of the Columbia River Gorge are well-known xamples (Willett and Sanders 1959).

For a bora to develop a strong pressure gradient must exist tween the interior and the coast. This difference can develop ther as the result of an arctic high-pressure area over the interior as a deep low-pressure area along the coast. Cold, continental air forced through river valleys. This falling air adds velocity to nd influenced by the pressure gradient. The falling, cold air gains me heat adiabatically, but this does little to offset the initial treme temperature difference, and the wind reaching the coast is ld relative to normal coastal air.[23]

In southeast Alaska, perhaps the best known bora-type wind is the ku. Taku winds blow predominantly from the northeast and occur most exclusively during the winter months. They are extremely rbulent, and gusts reach hurricane force.

In the Juneau area, local, extremely gusty winds may also result om downslope movement of cold air from the nearby elevated icefield. ring clear weather, radiative cooling produces a shallow layer of tremely cold air over the icefield which may spill over the seaward untain slopes in the form of katabatic winds. Such local winds ten occur during taku conditions. It should be noted, however, that is the deep breakthrough of cold arctic air from the Yukon and cKenzie Basins in northwestern Canada rather than the shallow, ld, surface air over the icefield that favors development of the ku (see footnote 23).

Considerable damage to property may occur from taku winds, and y pose great hazard to boats and aircraft. In the localized areas re they occur frequently, vegetation tends to adapt to these winds r time so that sudden damage to forest stands is rare. Annual age to stem and branch tips results in abnormal growth habits of es; trees tend to be short and highly tapered, with heavy root elopment, and crowns develop primarily on the leeward side of es. Trees offer mutual protection, and stands tend to be of uniform ght, with little opportunity for individual trees to extend higher

[23] Gordon D. Kilday. Taku winds at Juneau, Alaska. Undated report on file, ther Service Forecast Office, NOAA, Juneau, Alaska.

than the general level of the stand. In extremely exposed positions, trees may be gnarled or prostrate. Reproduction may be impossible in extremely exposed positions, and timberline is held at lower elevatic than on less exposed slopes nearby.

Thunderstorms

There are other types of winds strong enough to uproot trees, and they may account for the fairly rare blowdown that does not confc to the pattern established by general airflow. Although hemlock-spru forests are not in an area of general thunderstorm activity, thunders do occur, usually along the squall line preceding an advancing cold front. Strong downdrafts may develop during the later stages of a thunderstorm, hit the forest canopy or the ground with considerable force, then spread out laterally in the direction of least resistance. Velocities may reach 100 mi/h (160 km/h). Thunderstorm activity decreases northward along the coast, and in southeast Alaska thunderstorms are extremely rare.

Tornadoes

Tornadoes are rare in the Pacific Northwest but may occasionally damage forests and property. During the 1960's, three tornadoes occurred in the Puget Sound area of Washington (Feris 1970), and one struck the area of Portland, Oregon, and Vancouver, Washington, on April 5, 1972 (Porter 1973). Such "twisters" may destroy forests along a narrow track for several miles but do not cause widespread damage.

Wind Behavior Over the Forest

The general direction of storm winds is well known in most local or can be determined with little difficulty--for the forester, the best evidence is the orientation of windthrown timber. In many areas historical records of wind direction and velocity also are available. Wind direction of a particular storm is common knowledge to local weather observers, most pilots, and fishermen. A problem for the forester is to determine whether all storm winds come from approximat the same direction. Except for bora winds, the strongest winds in th hemlock-spruce type generally come from the southeast to southwest. The fact that they come from this 90° quadrant greatly simplifies the job of developing cutting programs to minimize damage.

Wind behavior over the forest is a complex phenomenon influence by the direction of airflow and its velocity, the relief of the land and the surface of the vegetation. Maintaining a smooth surface of forest canopy minimizes the amount of energy that can be transmitted to the trees and confines it to the tips of the trees (Fraser 1965). A rough surface, as in old-growth stands, causes more turbulent airflow; and much greater wind forces may be imposed on the exposed tree crowns. The rougher the surface the greater the reduction in airflow at the surface and the greater the turbulence in the downwin area.

Topographic Effects

The direction and velocity of the airflow may be changed by opography, and the forester should know where and to what extent this ccurs in an area. On windward slopes, changes in direction probably re less in the horizontal than in the vertical, with the airflow ending to go up and over a ridge rather than veer much to the right r left. The maximum directional change generally does not exceed 90°, s when winds flowing directly toward a vertical cliff veer upward, ight or left. Apparently, they do not change direction enough to ave an appreciable vector back toward the general airflow. The trong, continuing airflow itself seems to prevent this.

Velocity and turbulence of winds hitting a mountain ridge depend n the elevation of the mountain, steepness of slope, angle from which he winds come, and the general topography of the area (Hutte 1968). hen winds strike a ridge at right angles, the airflow is forced pward, causing vertical convergence of streamlines and increased elocity in the vicinity of the top. East-west ridges between coastal treams and southerly storm winds make this perpendicular approach a ommon one in the Oregon-Washington portion of the hemlock-spruce one. Resulting wind damage often starts on the crest of the ridge d extends some distance down the lee slope (fig. 55) (Ruth and der 1953). Heavy wind damage on ridges and upper lee slopes has en reported by several authors[24] (Alexander 1964, Gratkowski 1956).

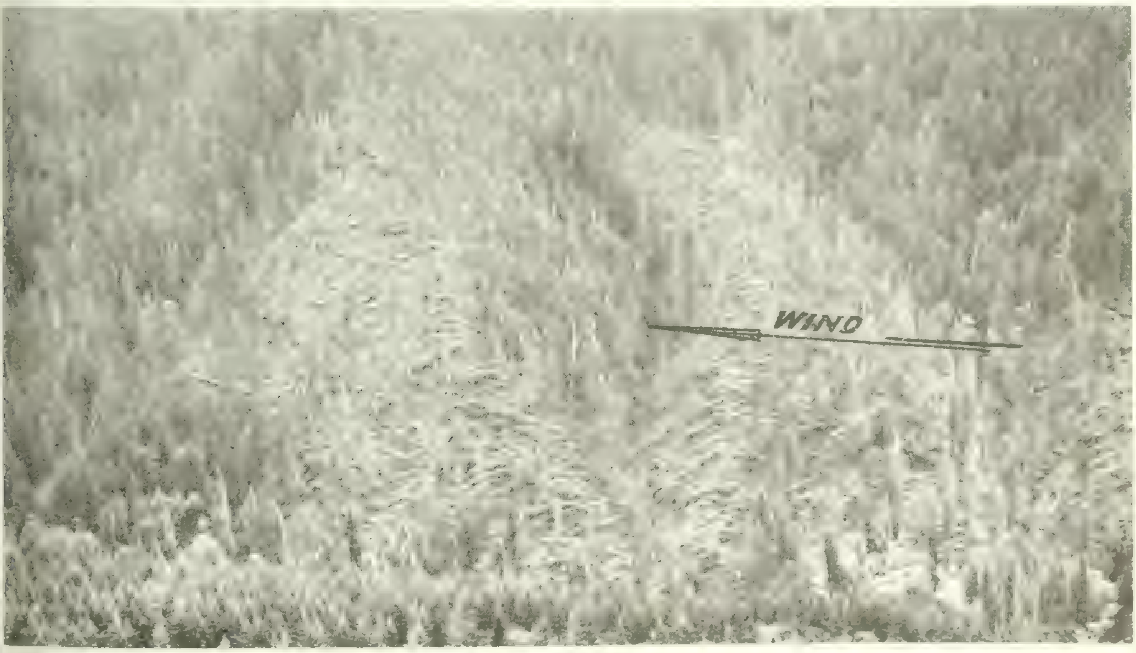

Figure 55.--Severe storm damage on the Siuslaw National Forest, Oregon. The wind blew up the main drainage from right to left. Damage is most severe on the lee slopes of secondary ridges.

24/ Pegues, J. J. 1959. The effects of windthrow on forest management on te farm license number seven. Unpublished thesis submitted to Board of Examiners, Aociation of British Columbia Foresters, Vancouver, B.C. 68 p. plus map.

Concentration of damage on gentle lee slopes apparently is due a lee-wave phenomenon, documented by studies in Britain (Gloyne 1968 Aanensen 1965). An airflow with suitable velocity and vertical temp ture gradient across a series of properly spaced ridges will develop sympathetic undulations, with strong surface winds induced to blow down lee slopes. Thus, strong winds may adhere closely to lee slope whereas only gentle winds may be apparent on windward slopes. Lee flow was common during the December 4, 1951, storm in the Oregon Coa Ranges, and most damage occurred on lee slopes. If slopes were over 70 percent, however, winds apparently did not adhere to them and there was little damage (Ruth and Yoder 1953).

A contrasting result occurred when the January 1968 wind damage Scottish forests, many of which were Sitka spruce plantations. The wind usually did not adhere to lee slopes over 10°, and only 7 perce of the damage was on lee slopes. Forty-five percent occurred on windward slopes or slopes oblique to the wind. Thirty-two percent w associated with funnels and ridgetops (Neustein 1971).

Wind patterns are generally more turbulent and erratic on lee slopes, but here too direction of fall in hemlock-spruce forests doe not indicate wide variations in wind direction during storms. Most uprooted trees have their tops pointed downwind, in line with the general airflow. When winds flow over a bluff, the lee side is prot from the direct force of the storm. The air below the rim may start to rotate and form a large, stationary roll eddy, with surface winds below the bluff actually blowing upslope opposite to the airflow ove the rim (Buck 1964). Such upslope winds apparently do not cause blowdown in hemlock-spruce forests. Timber in the lee of bluffs and very steep slopes generally is considered well enough protected from storm winds that it may be managed without serious risk of wind dama

When winds flow parallel to a ridge, velocity and turbulence ar greatest in the lower slopes. If the wind crosses a ridge obliquely, often there is turbulence near midslope and a channeling of wind direction along the slope (Hutte 1968). This is common in southeast Alaska and parts of British Columbia where storm winds tend to funnel up straits, inlets, and main canyons.

If a mountain protrudes above the general terrain, the airflow will pass around it as well as over the top and there will be an acceleration of windspeed on the shoulders. With a south wind, for example, windspeed will increase on the east and west slopes. There also may be increased velocity in the leeward area of the mountain, particularly if the topography is rising again in that area (Hutte 1 A similar acceleration of windspeed occurs when wind flows around th nose of a ridge.

The 1951 storm along the Oregon coast caused considerable wind damage on the tops of small ridges in the lee of a higher ridge and flats in the lee of a long, steep slope (Ruth and Yoder 1953). This latter phenomenon has also been noted in southeastern Alaska where t topography often rises steeply from the shoreline and then levels off to a gentle slope or flat. Trees on steep slopes often remain intac with most wind damage occurring on the flats to leeward. An added factor here is that the water table may be higher on flat areas, thereby limiting rooting depth.

Heavy storm damage may occur in and downwind from gaps and saddles in main ridges. Funneling of wind through such openings requires both vertical and lateral constriction of the airflow, with resultant increases in velocity (Alexander 1964, Buck 1964).

According to Brooks (1949), large vortexes (mountain tornadoes) may form in the lee of bluffs and steep slopes and develop wind rotational velocities over 100 mi/h (160 km/h). Apparently they are caused by friction of storm winds on mountain peaks and ridges. The circular pattern could cause trees to blow down in any direction.

Gentle, convective winds--such as land and sea breezes and valley and slope winds--and their interactions do not cause blowdown and have been disregarded in this discussion.

The Stand Border

Clearcutting a stand of tall trees in effect lowers the relief of the land and, at the same time, leaves a vertical but somewhat permeable wall around the perimeter of the opening. Depending on the size of the clearcut opening, the wind may dip down into it enough that some of the border is exposed to the full force of storm winds. Wind velocity in the center of an opening 50-tree heights across reaches 5 percent of velocity in the open (Flemming 1969). The airflow strikes border trees and is forced either over the forest canopy and, to some extent, under and through it, or it blows down the trees. If the trees remain standing, the greatest restriction to airflow is the foliage at canopy level. The flow is somewhat greater below the live canopy and above the understory vegetation than within the canopy itself (Bergen 1971, Raynor 1971). Most of the airflow, however, is forced abruptly upward. This flow tends to dip back down in a wavelike motion and may damage the interior of the stand downwind from the stand border. Some airflow is deflected right or left along the border.

tability

The first row of trees along a recently exposed stand border bears the brunt of storm winds. Tree stability depends, in part, on how uch exposure was actually increased by the harvest cutting. An ld-growth tree that has its crown above the general level of the orest canopy is well exposed to storm winds in the uncut stand. The ncrease in exposure may be limited to increased wind pressure on the ower bole, and its chances of survival are quite good. On the other and, a young-growth tree that has its crown below the general level f the canopy is well protected from storm winds by its neighbors. ull exposure leaves only limited chance for the tree's survival.

rientation

Storm winds blowing over the forest canopy dip down into clearcut penings, and most storm damage occurs on the lee or downwind side of he opening. This is illustrated by observations on the Cascade Head xperimental Forest after the storm of December 4, 1951. Winds were rom south 30°W. Ninety-three percent of the storm damage occurred

along the north and east boundaries of eight clearcuts compared with only 7 percent along the south and west boundaries.

Cutting boundary	Number of damaged trees	Percent of volume
North	461	44
East	568	49
South	29	3
West	63	4

In general, it appeared that if the northeast cutting boundary was on a windward slope, there was less blowdown than if it was on a leeward slope (Ruth and Yoder 1953). A similar pattern was observed on 55 clearcuts in the Oregon Coast Ranges and has been reported in other timber types (Alexander 1964, Boe 1966, Neustein 1965; also see footnote 24, page 133).

Length

Small clearcuts, per acre harvested, suffer more wind damage than large clearcuts. Two main factors are at work. One is the consistent reduction in airflow as an opening becomes smaller. For example, the airflow at midcrown level at the center of a 1-acre (0.4-ha) clearing is 40 percent of that in a 10-acre (4-ha) clearing. The other factor is that small openings, per acre harvested, have more perimeter than large ones. For example, a square 40-acre (16-ha) clearcut has 1 mile (1.6 km) of cutting boundary. The same acreage harvested as 80 half-acre (0.2 ha) clearcuts has 9 miles (14 km) of cutting line exposed to wind damage. The effects of longer cutting boundaries associated with small clearcuts generally outweigh the reduction of wind velocity (Neustein 1965, Neustein et al. 1968). Therefore, clearcutting many small areas rather than a few large ones is likely to increase wind damage. Also, small clearcuts allow less flexibility in selection of locations for windfirm cutting boundaries. On the other hand, openings may be made so small that the wind does not dip down into them enough to cause damage. In hemlock-spruce forests these openings would probably be classed as thinning or group selection cuttings rather than clearcuttings.

Channeling Effects

Acting as a wind barrier the stand border may funnel the wind, much as the walls of a narrow valley would. If the wind is funneled into a narrow pocket or vee, the velocity is increased and damage may occur at the apex (Alexander 1964, Gratkowski 1956, Curtis 1943).

A road right-of-way also may lead to storm damage. If a straight section of the road parallels storm winds, the wind may funnel along the right-of-way with increased velocity and cause damage where the road turns. Examples of wind damage along straight roads connecting nearby clearcuts are common.

Winds that blow across rather than along rights-of-way may also cause damage. Munger (1946) observed damage along an east-west ridge road in coastal Oregon where winds were from the south to southeast.

e found 5.8 times more trees uprooted or broken within 100 ft (30 m) f the right-of-way than within 100 to 200 ft (30 to 60 m). This 30- o 100-ft (9- to 30-m) wide opening significantly increased wind amage. Inspection of rights-of-way in a forest stand can be a guide o local wind hazard.

he Windfirm Stand Border

Most natural hemlock-spruce stands have a windfirm stand border hat develops with the stand and protects it from wind damage (fig. 56). hese borders are readily seen along waterways and around meadows or uskegs. They are roughly wedge-shaped and are best developed where heir leading edge points into storm winds. At the perimeter, they egin with native ground vegetation. This provides wind protection or establishment of shrubs which then grow taller and provide protection or tree seedlings. These usually are Sitka spruce or lodgepole pine hich may develop into gnarled, windswept specimens. Back into the tand, the trees grow progressively taller, each tree protected by rees to windward. The timber stand soon reaches maximum height for the site, after which environmental factors other than wind limit growth. The wedge-shaped stand border lifts storm winds up and over the timber stand and generally is quite effective in protecting it from wind damage. Also, there is less tendency for the wind to dip down into the interior of the stand than when the stand border is vertical. If the trees along the leading edge are felled, the next high wind can be expected to damage exposed trees, which have not become adapted to wind stresses (Whitehead 1968).

'gure 56.--A windfirm stand border facng the beach at Yakutat, Alaska. early all trees in this border are itka spruce.

Wind Resistance of Trees

Windfirmness of a forest tree is determined mainly by the force of the wind on the crown versus the inertia of the soil mass gripped by the root system. When a storm is of only moderate intensity and duration, almost all the trees that uproot will be those with poor anchorage. Trees with deep sinker roots generally resist the wind and remain standing. They are, however, susceptible to uprooting or stem breakage if the wind is strong enough. The forces of

the wind may be approximated by the percentage of broken trees. If high percentage are broken, the wind was an unusual one of truly hurricane force. If most trees were uprooted, probably the wind wa less severe.

In general, trees become less wind resistant as they grow tall (Andersen 1954). The turning moment at the base of the tree increa with the length of the lever arm, top weight generally increases relative to root weight, a larger crown has more wind resistance, a a heavier crown leaning in wind puts more tension on the root syste These and other factors account for generally more storm damage wit increasing tree height.

Winds impose bending stresses on the roots and boles of trees thus stimulate growth conducive to windfirmness (Andersen 1954). Accelerated growth occurs on the lee side of conifers (Laitakari 19 Bannan and Bindra 1970, Busby 1965). Many hemlock and spruce exami in exposed situations on the Oregon coast showed large, strong, sup roots on the lee side; and stumps had accelerated radial growth on that side of the main stem (figs. 57 and 58). In contrast, Fraser Gardiner (1967) did not find this tendency in young Sitka spruce plantations in Great Britain.

Figure 57.--A dominant Sitka spruce tree on a ridge exposed to southerly winds. The north side of the tree is buttressed at the base on the leeward (north) side. Cascade Head Experimental Forest, Oregon.

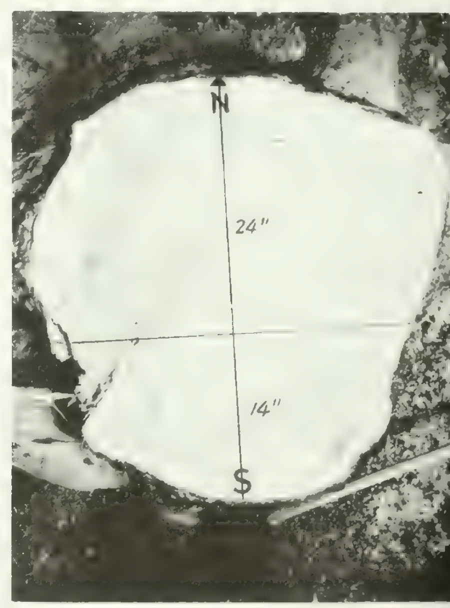

Figure 58.--Looking down on the stump of the tree shown in figure 57. The stump shows increased radial growth on the lee (north) side. Cascade Head Experimental Forest, Oreg

Open-grown trees tend to be short and have rapid taper and lar low crowns. On the other hand, trees growing in the interior of a stand receive little stimuli from the wind and do not develop much windfirmness. They are especially vulnerable to damage when expose along a cutting line.

Dominant trees growing in deep, well-drained soil tend to be more indfirm than trees in other crown classes. Their crowns reach above he general level of the forest canopy where they receive stimuli from revailing winds. The deep soil permits development of strong root ystems.

Tree pulling experiments by Fraser and Gardiner (1967) on plan- ation-grown Sitka spruce in Britain showed no measurable difference n resistance to overthrow between trees pulled upslope and trees ulled downslope.

Bending of tree boles during storms may cause structural weakness nd more susceptibility to breakage during subsequent storms. Breakage f 30-year-old Sitka spruce in Britain occurred at bulges on one side f the stems. Investigation revealed the bulges to be fast-grown ompression wood overlying a natural compression failure and associated ing shake. The bulges were attributed to bending during severe torms 2 years earlier (Forest Products Research Board 1964).

Soil Effects

Poor anchorage of trees generally results from shallow rooting. his may be due to shallow soil underlain by bedrock, an impermeable ayer near the soil surface, or a high water table--the latter being ost common in hemlock-spruce forests. It is not known what amount f excess soil moisture damages the roots or its duration, but it is lear that prolonged saturation will restrict rooting to the soil bove the saturated layer. Under severe conditions, rooting will be estricted to the familiar flat plates seen on uprooted trees (fig. 59) raser and Gardiner 1967).

Figure 59.--Uprooted western hemlock showing typical flat, platy rooting structure when grown on poorly drained soil.

Surveys in Sitka spruce forests in Britain have established a direct relationship between rooting depth and windfirmness which has been confirmed by tree-pulling investigations (Pyatt 1966). General observations and surveys indicate that the same relationships hold true in North American hemlock-spruce forests (Ruth and Yoder 1953).

There are significant differences in tree stability, depending o soil texture. Under moist conditions, trees growing in sandy soil ar more difficult to pull over than trees growing in loam. Trees in loa soil are more stable than those in clay soil (Busby 1965, Fraser 1962 Fraser and Gardiner 1967, Pyatt 1966). The shear strength of most soils is reduced as moisture content increases; clay soils particular lose strength when waterlogged (Busby 1965). Coarse-textured soils with large pore spaces, free drainage, and no compacted horizons are favorable for deep rooting.

Heavy precipitation or rapid snowmelt will saturate the soil whenever the rate of water entering the soil exceeds the infiltration rate into the subsoil. The most critical situation seems to be where an already high water table is raised still higher by heavy precipita Water makes the soil more pliable and less shear resistant and thereb reduces the stability of tree root systems.

Soils having a high water table often can be recognized by plant indicators. Skunk cabbage is a reliable one (Minore 1969b). Other species, such as western water hemlock, water parsley, and western golden saxifrage may also be used.

Storm winds often occur along with heavy precipitation, exerting maximum pressure on tree crowns when the soil is saturated. Single gusts may be strong enough to uproot trees, but often it is the combi nation of windspeed and duration of the storm that causes damage. Th process is described by Hutte (1968) for Norway spruce in Germany. I wet, poorly drained soils, the main roots extend laterally, and verti cal roots are absent or extend only a short distance into the subsoil As trees sway in the wind, the windward roots may be lifted enough to separate from the mineral soil; each tree then depends on leeward roots to hold it upright. If leeward roots are thin, the tree uproot as soon as windward roots are separated from the soil. If leeward roots are strong, movement is transferred to the root plate which rises and sinks with strong gusts. As it rises, water runs into the cavity vacated by the roots. As it sinks, water and soil particles bubble out from under the plate on the windward side. The water tend to filter back under the plate but the soil tends to be deposited in ring around its windward perimeter. Part of this soil comes from the windward part of the plate, but the greater part from the lee side where leeward prop roots are pushed deeper and deeper into water-lubricated soil. These leeward roots finally break, usually 4 to 8 ft (1.2 to 2.4 m) from the main stem as the tree is overthrown by a strong gust. Thus, when rooting is shallow, it is not only the wind velocity but the duration of the storm that determines wind damage.

The process is different on deep soils. A root plate generally is absent, and the root-soil mass scarcely moves during windsway. Most movement is limited to bending of the main stem. Unlike the situation where tree roots are shallow, the duration of the storm has little effect. If gusts are strong enough, stem breakage rather than uprooting will occur. Most situations are intermediate--wind damage is a combination of uprooting and stem breakage.

Topographic drainage is an important factor. When forest soils ave at least moderate slope, water tends to flow downhill and away. he ground water table usually remains well within the soil; or if t rises, it recedes rapidly, doing little damage to the root system. n level ground and gentle slopes, water drains away more slowly, amage to the root system is greater, and trees are less stable. uring storms or rapid snowmelt, the water-saturated soils become emiliquid and an insecure anchor for trees (Day 1950).

Freezing of soil is also a stabilizing factor in the northern ortion of the hemlock-spruce forests. In the mild climate of Oregon nd Washington, there is little soil freezing and trees are rarely tabilized by their roots being cemented in a mass of frozen soil. In laska gale-force winds are most common from September to December hen soils under forest stands are usually unfrozen; however, gales ometimes occur during the winter when soil is frozen. Patric (1967) eported that soil was frozen to a depth of 15 in (38 cm) during inter under a forest stand near sea level in the Juneau area. When oots are stabilized by frozen soil during strong gales, stem breakage ay occur more commonly than uprooting.

Decay

Diseases may destroy part of the root system of a tree and thereby ecrease its resistance to windthrow. Some hemlock-spruce sites have fluctuating water table within the rooting zone. It recedes during he growing season, allowing small roots to penetrate deeper into the oil. When the water table rises around these roots during the winter, hey often die from lack of aeration. The same process may occur over longer term, with roots penetrating into deep soil during dry years, nly to die back during an ensuing wet period. This recurring root ortality provides a continuous entry court for disease; and, according o experience with Sitka spruce in Britain, disease is more prevalent areas having a high water table. A bunchy development of roots at he top of the impeded zone was reported by Day (1953) as evidence of oot dieback in Sitka spruce.

Mortality of many individual trees that uproot or break off in e uncut stand or along a stand border may be attributed to wind mage, with decay often the primary cause. Ruth and Yoder (1953) und decay to be associated with at least 15 percent of the wind mage in hemlock-spruce in western Oregon. Even greater percentages ve been reported in other timber types (Gratkowski 1956, Alexander 64, Wiley 1965).

Hemlock and spruce may be damaged as trees sway in the wind and e roots rub against rocks in the soil. This is a common occurrence windy areas where trees have restricted roots. The root plate ises and lowers during windsway, and underlying rocks abrade the roots. nker roots are particularly vulnerable. They move endwise and may pushed directly into rocks where they develop frayed ends (fig. 60). milar root damage has been noted by Day (1950) on Sitka spruce in itain. Such root damage provides a ready entry court for disease ganisms. Damage tends to be less when trees are deeply rooted. The rge soil mass gripped by the roots tends to limit windsway to bending the main stem, and there is less movement of roots within the soil.

Figure 60.--Abrasion and frayed ends of sinker roots of Sitka spruce produced by movement against rock during windsway.

Stems broken by the wind and fresh-cut stumps left from salvage of blowdown provide entry courts for disease. For example, viable spores of *Fomes annosus* were found following the 1968 blowdown in Scottish forests, and stumps were treated with sodium nitrite to prevent infection (Burdekin 1971).

Exposure

There is a close correlation between general exposure of trees to torm winds and their windfirmness (Andersen 1954). Trees in an xposed stand border tend to be shorter and have more taper and stronger oot systems than trees in the interior of a stand. Even though more xposed, they may survive a strong gale while the interior of the tand suffers severely (fig. 61).

Figure 61.--Many exposed trees along this beach fringe survived a strong gale while trees behind them were blown down. Zarembo Island, Alaska.

Exposed trees do suffer damage. Trees that grow in exposed lcations develop great stability if soil conditions permit; but they to may have restricted rooting depth, suffer from root rot, or have oher deformities. A major hazard exists when trees are exposed by hrvest cutting or other events and gale-force winds occur before they icrease in windfirmness.

Species Differences

There appear to be basic differences in wind resistance among the secies. Western redcedar often is reported as most windfirm, followed b Douglas-fir, Sitka spruce, western hemlock, and Pacific silver fir (byce 1929, Gratkowski 1956). In many cases, however, observed

differences result from site preferences. Douglas-fir prefers well-drained sites which generally permit deep rooting. Hemlock and spruce, on the other hand, are often in the wetter areas where the water table restricts rooting depth. For similar soil conditions, Eis (1974) found root systems of western hemlock, Douglas-fir, and western redcedar to be very similar. Apparently much of the differen[ce] in tree stability noted in the field is due to site conditions.

Stands of red alder with an occasional hemlock or spruce extendi[ng] above the alder canopy appear to be very windfirm, and little storm damage has been noted (Ruth and Yoder 1953). Plantations of spruce and Scots pine or lodgepole pine have been established in Wales, but apparently they are no more stable than pure Sitka spruce which i[s] widely used as the most suitable tree in windswept areas. Sitka spru[ce] has been planted widely except on dry knolls, areas where *Fomes annos[us]* is prevalent, and areas in east Wales where rainfall is less than 40 in (100 cm) per year (Stumbles 1968).

Stand Density Effects

Isolated and widely spaced trees often survive the worst of storms, yet thinning to increase tree spacing often leads to severe storm damage. Some authors favor no thinning in windswept areas (Stumbles 1968, James and Dier 1968); others report that thinnings will improve windfirmness (Alexander 1964, Fraser and Gardiner 1967, Crawford 1968, Stroempl 1971). Soil conditions, thinning intensity, type of thinning, and time usually are the key factors.

On well-drained soil permitting good depth for roots, thinning is believed to increase tree diameter and root growth and to cause trees to become more windfirm. Where rooting depth is restricted, thinning apparently encourages lateral extension of the root system but not vertical extension. This was the case on gley, peaty gley, and deep peat soils studied in Britain. In fact, rooting depth in thinned stands on such soils may be less than in unthinned stands (Fraser and Gardiner, 1967, Pyatt 1966). Fraser and Henman (1966) pulled over trees in lightly and heavily thinned plots and found the root systems after heavy thinnings to be significantly wider but shallower. Thinning did not improve a tree's resistance to being pulled over.

Thinning intensity governs the degree of exposure of trees left standing. An isolated tree fully exposed to the wind is stimulated to develop a strong root system. The crowded tree, on the other hand, depends on its neighbors for much of its protection. It struggles upward for light and develops a high root-top ratio. Removing its neighbors increases its exposure to storm winds, the degree of exposure depending on thinning intensity.

Type of thinning has important effects on subsequent stand stability. Thinning from below by removing mostly suppressed and intermediate trees does little to increase wind exposure of remaining crop trees. On the other hand, thinning from above exposes trees in the lower canopy which previously were protected from storm winds. Two Sitka spruce stands were thinned in Great Britain by removing 30 percent of the standing basal area, in the first by cutting dominant and codominant trees and in the second by removing only small-crowned trees from th[e]

lower canopy. Unthinned plots provided a third treatment. Subsequent blowdown was greatest in the stand thinned from above and least in the unthinned plots, indicating that thinning from above is undesirable in windthrow-susceptible areas (Low and Taylor 1967).

Time is the other key factor. Thinning suddenly exposes trees of the residual stand, and growth of their roots and main stems are stimulated. But this takes time, and many years will pass before their stability approaches that of a long-isolated tree. Therefore, trees left after thinning initially are more vulnerable to wind damage than had there been no thinning.

Predicting Wind Damage

The probability of wind damage in a particular forest area can be estimated by observing tree anchorage, frequency and intensity of storm winds, tree height, exposure to storm winds, and local history f blowdown. Predictions may then be made of the height to which a tand may safely be grown before wind damage will make it impractical o carry it farther.

The recent blowdown history of a forest area may be observed and sed as an indicator of blowdown to be expected in the future. Obser- ations are easiest to make prior to salvage; but the uproots remain or observations later, if necessary. It is even possible to get a eneral idea of frequency of wind damage by observing the various tages of decay of windthrown trees or uproots.

The direction of fall indicates the direction of storm winds. ome trees are knocked down by others and may not fall directly down- ind. Gratkowski (1956) estimated that in one storm about one-fifth f the trees were knocked down, the percentage of understory trees reater than the dominants. General direction of fall is easily bserved from an airplane, from a vantage point, or from aerial hotographs.

The portions of an area most susceptible to blowdown may be dentified by above-average frequency of blowdown. Absence of recent lowdown, on the other hand, is only partial assurance that storm amage is not a problem. The stand may be vulnerable to damage, ut recent storms may have bypassed the area. Unusual storms may ring high wind velocities to previously sheltered areas.

Long-term blowdown history probably is the best measure of blow- own hazard. This can be estimated from the mound-and-pit microrelief an area. When a tree uproots in the wind, the mass of soil material termingled with the root system generally is moved upward and laterally ward the direction of fall, leaving a pit which may be 2 to 3 ft .6 to 1 m) deep and several feet in diameter. As the tree roots cay, the displaced soil material is deposited in a mound generally the leeward side of the pit (fig. 62). If there is no history of nd damage in an area, wind may be disregarded in management planning.

Shallow rooting being a major factor in wind damage, an important rt of predicting blowdown hazard is to obtain detailed knowledge of oting depth. A soil survey with special attention given to rooting

Figure 62.--Mound-and-pit topography. Depressions in the ground and the adjoining mounds indicate windthrow of trees which have since disappeared; 100-year-old Sitka spruce stand, Cascade Head Experimental Forest, Oregon.

depth will be very helpful in planning harvesting operations. Genera y soil surveys are not detailed enough to locate small groups of shallov rooted trees, as near a spring or small seepage area. These may be identified in the field during reconnaissance or location of cutting lines.

Wind damage can be expected in areas where wind velocity is accelerated by topography. As mentioned earlier, these include the shoulders of a mountain, nose of a ridge, lee of a saddle or gap in a ridge, small ridges in the lee of a higher ridge, and on flats downwi from steep slopes.

Tree height is an important factor. An area may be vulnerable t storm damage, yet safe for the time being because the trees are small For example, Malmberg (1965) found that stands less than 100 ft (30 m tall, both unthinned and thinned, generally withstood the severe stor of October 1962.

Predictions of wind damage have been made with Sitka spruce in Great Britain by linking up two kinds of information. The first is wind tunnel data on the force of wind on trees. Force varies with wind velocity and tree size. The second comes from field measurement of the force needed to pull over trees. This varies with tree size and soil type. Both kinds of data can be expressed as the turning moment at the base of a tree. Curves showing the relationship betwee critical wind velocity and height of trees growing on various soils have been developed. For example, a wind velocity of 40 knots (74 km per hour becomes critical for a tree 70 ft (21 m) in height growing on a brown earth, 60 ft (18 m) on deep peat, and slightly more than 50 ft (15 m) on a surface water gley (Fraser and Gardiner 1967). Probability of windthrow associated with tree height in Wales has resulted in a recommendation to harvest Sitka spruce on exposed sites with gley or peaty gley soils when trees reach 55 ft (17 m) in height (Stumbles 1968).

Shorter rotations and therefore shorter trees are being dictated by economic conditions. There are many areas where wind damage has been a problem in overmature stands but where trees in intensively managed stands will be cut before reaching wind-susceptible heights.

Reducing Wind Damage

Wind damage can be reduced substantially by silvicultural practice but cannot be eliminated. One approach is to shield susceptible trees from the wind by leaving buffer strips of windfirm trees or by progressive strip cuttings toward storm winds. Another approach is to improve stability of individual trees by increasing rooting depth, strengthening the bole, or lowering the center of gravity of the crown. Rooting depth may be increased by improving soil drainage. Strengthening the bole and lowering the tree's center of gravity can be done through thinning and tending for many years. These measures are costly and are limited to young stands. Trees may be cut as they grow to wind-susceptible heights. It is helpful to minimize the length of cutting boundary exposed to storm winds. This can be done by harvesting large clearcut units, considering, of course, other factors that may limit unit size. Large units also permit more flexibility in locating stand borders in windfirm locations. Some damage will occur in spite of all precautions that may be taken, so it is wise to locate roads near high hazard areas.

Protecting Wind Hazard Areas

When areas to be logged are laid out, an initial step is to identify areas with shallow-rooted trees, high wind velocity, and a history of wind damage. A second step is to determine the direction of storm winds. Winds may follow the general pattern, from southeast to southwest; or they may be redirected by local topography. There may be a strong potential for east wind; for example, near the mouth of the Columbia River between Oregon and Washington or near the Stikine or Taku Rivers in southeast Alaska.

When the hazard area is identified, one alternative is to harvest all the trees within it at one time and to take care that the cutting boundary on the lee or downwind side of the clearcut is in a more stable stand. Another alternative is to leave the entire area uncut, with a stable stand or edge to windward for protection. Usually a satisfactory alternative is to harvest the downwind portion of the hazard area if the downwind cutting boundary is on high ground. This leaves the upwind stand border of wind-susceptible trees exposed but on the windward side of the clearcut where the border trees are protected by the stand to windward. This is not a satisfactory alternative if the area is also subject to occasional storm winds from the opposite direction. An example would be when the main damage comes from southwest storm winds but occasional damage results from easterly or northerly bora winds. The least desirable alternative is to harvest the upwind portion of the area. This leaves a border of susceptible trees fully exposed to storm winds and invites maximum storm damage.

Special care should be taken if clearcut boundaries are to be located in areas where airflow will be accelerated by topography.

Cutting areas should be arranged to avoid leaving exposed stand borde in such locations. Where this is not possible, the exact location of the cutting line should be selected with great care to make it as windfirm as possible. Boundaries on the windward side of clearcuts--numbers 1, 3, 5, and 7 in figure 63--are protected by the trees to windward and should be more windfirm than boundaries on the lee side of clearcuts--numbers 2, 4, 6, and 8. Since storm damage in uncut stands is more common in the lee of a ridgetop, boundary 2 should be considerably more windfirm than boundary 4 (Ruth and Yoder 1953). Boundary 6 probably is more windfirm than boundary 8 in figure 63 because lee flow probably will not follow down a slope as steep as th one illustrated. In gently rolling topography on a lee slope of a ridge, boundary 6 probably would be less windfirm than boundary 8 on windward slope.

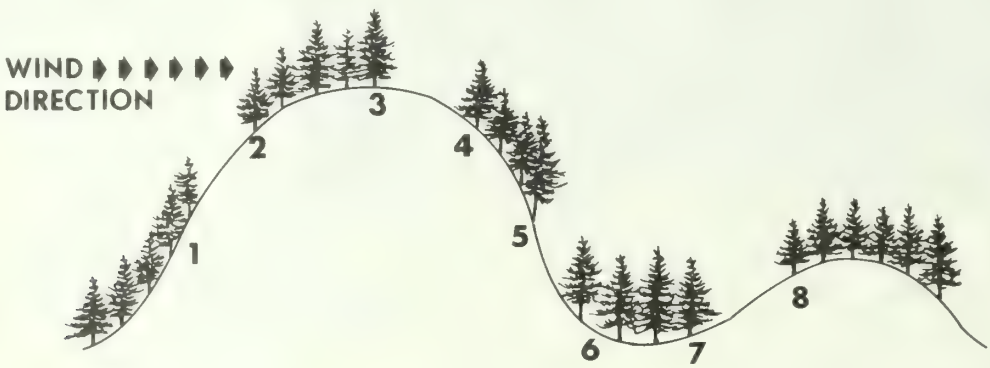

Figure 63.--Vulnerability of clearcut boundaries to wind damage. Boundary numbers 1, 3, 5, and 7 are protected by trees to windward and can be considered more windfirm than numbers 2, 4, 6, and 8.

Locating Cutting Lines

Careful location of cutting boundaries is very effective in minimizing wind damage. One of the first rules is to avoid funneling storm winds through a narrow opening or into a corner, which would increase wind velocity and thereby invite damage. If storm winds are likely to parallel a boundary, the boundary should be as straight as practicable. Avoid changes in direction that expose border trees to the wind. It is best if the boundary angles away from the downwind direction. This way winds will blow over the stand and into the cutover area rather than vice versa in which case trees would be full exposed to the wind. To be effective, such an arrangement could vary from a straight line perpendicular to the wind to a "V" with the apex pointing into the wind. Of course, should winds blow from the opposi direction, they would be funneled into the apex of the "V" and could cause damage.

Young conifers, alder or other hardwoods, scrub stands as found near a muskeg, and mixed alder-conifer stands are generally windfirm and make good stand borders to leave exposed to storm winds. Cutting areas should be arranged so that windfirm stands form the exposed cutting boundary.

Just as the general location of an exposed cutting boundary may be selected to minimize wind damage, so may the specific location.

Much may be accomplished by moving the cutting line only a short distance nearer to or farther from the landing so that wind-susceptible trees will be harvested and the most windfirm trees left exposed along the cutting line. Windfirm trees are those in the upper crown classes--deep-rooted trees, cedars, Douglas-fir, Sitka spruce, trees without root or stem rot, and trees without damage to the root system. Often they are characterized by large leeward prop roots, indicating a buildup of wind resistance.

Trees whose root systems have been damaged by road or fireline construction or for tail holds in grapple yarding operations are poor risks and should be removed during logging. It is best, of course, to locate the road or the fireline far enough within the cutting area that root damage does not occur to residual trees.

Progressive Strip Cutting

Progressive strip cutting toward storm winds minimizes storm damage on the lee side of clearcut areas. The method was developed in Europe early in the 19th century (Troup 1952); its use with wider strips has been recommended for Western United States forests (Alexander 1964, Boe 1966), including the hemlock-spruce type (Ruth and Yoder 1953). The objective is to avoid creating a lee cutting boundary in stands exposed to storm winds. This is done by cutting the first strip roughly perpendicular to storm winds and immediately windward of a windfirm stand or a natural opening, such as a meadow, muskeg, or open water. After the first strip is regenerated, a second strip is cut windward of the first, and so on progressively into the wind. Cuttings are timed to progress across the area in a rotation. At the end of the rotation the profile of the regenerated stands forms a wedge, pointing into the wind which lifts the airflow up and over the stand (fig. 64E). Cutting of the new crop begins where the first strip was cut and similarly progresses into the wind.

If no opening is available as a starting point for progressive strip cutting, a logical location is the downwind boundary of the ownership, usually the north or east boundary. If cutting must begin within a hemlock-spruce stand, a windfirm location should be picked for the boundary, just as should be done anywhere border trees are to be exposed. In any event, no more than a single stand border will be exposed for the entire progressive strip cutting cycle. This compares with many miles of exposed stand border left by

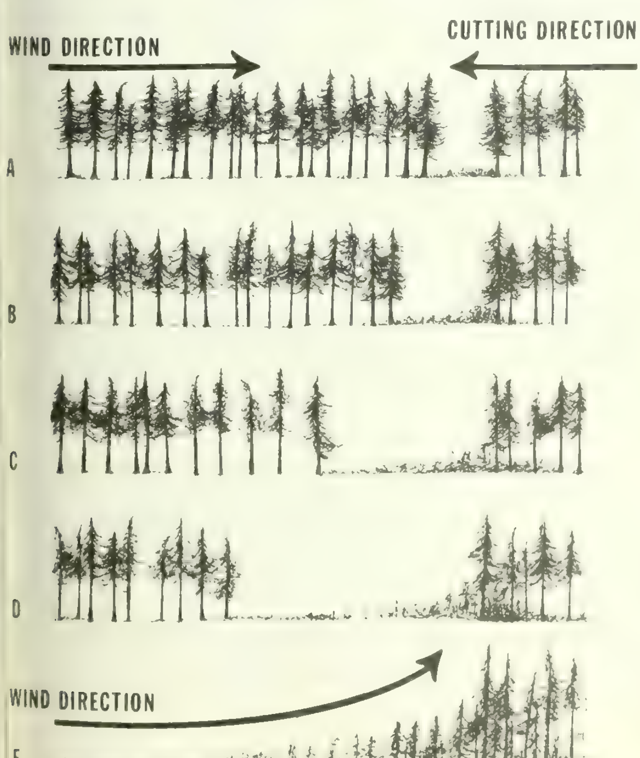

Figure 64.--Progressive strip cutting into the wind to develop a windfirm stand border (see text).

patch cutting. In many cases strip cutting will prove impractical, but variations may be used to fit local conditions. One variation is to harvest alternate clearcuts along the strips and thereby leave a seed source on three sides. When these clearcuts have regenerated, the intervening timber is cut and alternate clearcuts are harvested in the second strip. This approach was fitted to an uneven ownership pattern along the northeast boundary of a progressive strip demonstration on the Cascade Head Experimental Forest (Ruth and Yoder 1953).

Timing of strip cuttings may be varied to meet local needs. Often the next strip to be cut is needed as a seed source and cutting is delayed until regeneration is obtained. In Alaska, the cost of setting up a logging camp may limit harvest cutting to only a few entries per rotation. Elapsed time between strips may be many years, but progressive strip cutting still is possible by harvesting the downwind portions of the area first and progressing into the wind with successive cuttings

Developing Windfirm Stand Borders

Windfirm stand borders may be developed by progressive cutting in very narrow strips (Troup 1952). The first strip is harvested immediate windward of the stand to be protected and should be wide enough that exposed border trees will be stimulated to become more windfirm, but not so wide that they will be broken or uprooted (fig. 64A). Local experience with storm damage along road rights-of-way perpendicular to storm winds can be used as a guide for strip width. Natural regeneration or planted trees that become established in this first opening are the beginning of the windfirm stand border. Border trees in the stand to be protected, now receiving more light, will retain and develop lower branches.

As soon as these border trees become more windfirm, a second strip may be harvested (fig. 64B). Trees should be felled within the strip to avoid damaging regeneration established in strip 1. The additional light stimulates regeneration in strip 1 to accelerate height growth. New seedlings become established in strip 2. The increased exposure of border trees to wind provides added stimulation to develop windfirmness. Successive strips are cut to windward over a period of years, the timing depending on stability of the border trees in the stand being protected and on height growth of the new stand (fig. 64C). The slower the rate of cutting to windward the steeper the profile of the new windfirm stand border. When protection afforded by the young border stand and the increased windfirmness of border trees in the original stand are sufficient, the windfirm stand border is considered establishe The timber stand to windward may then be clearcut or otherwise treated as desired. The original leeward stand now is protected by a windfirm border that lifts storm winds up and over the edge of the stand (fig. 64

A similar procedure may be used with shelterwood cutting. In a two-cut shelterwood, for example, strip 1 receives a shelterwood cut. After regeneration is established in the shelter of the remaining overstory, the overstory is removed, and strip 2 receives a shelterwood cut. Additional cutting of shelterwood strips progress to windward in the same manner as for clearcut strips.

There have been several attempts in Europe to develop windfirm stand borders by severe pruning. About three-fourths of the crown of

edge trees may be removed. Severity of pruning decreases toward the interior of the stand until at about 150 ft (45 m) from the edge pruning stops. Pruned trees are more stable because they have less crown area, yet they break the wind and protect the interior of the stand. Several variations of this technique, such as topping the trees or pruning all windward branches, have been tried but none have been successful enough to become standard practice (Busby 1965, Neustein et al. 1968).

Stumbles (1968) described a technique used in Wales designed to improve stability of trees that will later be exposed along a stand border. Several years in advance of harvest cutting the cutting boundary is located on well-drained soil where exposure of trees may be expected to improve their windfirmness. Windfirm trees are selected in the first 130 ft (40 m) within the stand that will be exposed to the wind. Surrounding trees are then harvested in a heavy crown thinning. This allows several years for trees that will be exposed to adapt to increased wind pressure. If the stand to be exposed is young, a 66-ft-wide (20-m) strip of the older, windward stand is harvested several years in advance; this gives border trees of the young stand time to adjust to increased wind pressure.

Stabilization of a Stand Border After Wind Damage

In many situations wind damage associated with harvest cuttings tends to diminish with time (Ruth and Yoder 1953; Weidman 1920; Alexander 1964, 1967; Busby 1965). The more susceptible trees are uprooted or broken soon after exposure, leaving only the more windfirm trees standing. These tend to build up windfirmness. If leaning trees are left by the storm, they remain susceptible and continued mortality can be expected (Wiley 1965).

The scattered trees that remain standing along the edge break the wind and provide some protection for trees to leeward. Farther in, more remain standing and these, in turn, divert more of the wind. This process continues until the wind is again lifted up and over the forest canopy. When the wind filters through a border of widely spaced and well-rooted trees, rather than being forced up and over a fully stocked stand edge, it is less likely to eddy down and strike inside the stand.

If a few additional trees blow down in subsequent storms, it may be best to salvage down, damaged, and leaning trees only, being careful to avoid damaging roots of trees to be left. Several salvage efforts may be needed before the line stabilizes. Many factors will influence salvage attempts. For example, repeated salvage is impractical at remote locations in Alaska but is easily accomplished in readily accessible areas in Oregon and Washington. The decision will also be affected by availability of equipment, market conditions, and cutting schedules.

If the stand border is located where tree stability is poor, it is best to harvest the remaining trees and move the cutting line to a more windfirm location. Fraser (1965) found that wind damage on poorly drained peat soils in Britain, once started, tended to continue at an accelerating rate and frequently stopped only when there was a change in soil type, tree size, or forest type.

Improving Tree Stability

Experience in Great Britain and elsewhere has shown that when poor drainage restricts rooting depth, resistance to uprooting can often be increased by silvicultural treatment. A high water table can be lowere by drainage, thereby improving rooting depth and mechanical strength of the soil. Drainage has been particularly successful in deep peat soils in Great Britain, because it not only increased rooting depth and windfirmness but also improved yield capacity (Taylor 1970, Stumbles 1968). Soil drainage is best accomplished at the time of planting but still remains a profitable operation in Britain up to 10 years afterwar (Fraser 1965). Some soils, however, will not drain properly even with ditching (Day 1953). Within the hemlock-spruce type, attempts to increase windfirmness by improving drainage have not been made.

Just as any action that lowers the water table increases tree stability, any action that raises it can be expected to cause root dieback and loss of stability and may provide an entry court for diseas An example, particularly disastrous in flat topography, is plugging a stream channel with logging debris. Dams made by beavers, construction of reservoirs, and removal of vegetation can cause similar problems. The effect on the water table and subsequent wind damage and root disease should be considered.

Leaving dense stands unthinned affords maximum protection of each tree by its neighbors. If the stand border is destroyed by wind or other disturbance, however, damage is likely to spread through the stand. If thinnings are prescribed, they should be done early in the life of the stand and tested on a small scale until results can be ascertained. A single precommercial thinning may be all that is appropriate in wet areas. If treatments can be applied to lower the soil water table, rooting depth should improve, and subsequent thinnings may be practicable.

It is advantageous to thin exposed stands after the season when high winds occur and prior to the growing season. This gives the residual stand at least one season to build up windfirmness before exposure to storm winds.

Salvaging Blowdown

Organizing for salvage of windthrown timber varies considerably, depending on the extent of damage. Salvage of catastrophic blowdown is usually coordinated by a committee made up of governmental agencies and interested parties. A necessary first step is to determine the location and magnitude of damage. Usually this is done by aerial survey, and the blowdown areas are sketched on a map. Later the areas are examined on the ground by the timber owner and detailed salvage plans made. The volume to be salvaged may exceed the allowable cut and mill capacity for the local area. Then consideration must be given to transporting logs outside the area and the effect this will have there.

Salvage of casual blowdown normally is a concern only of the timber owner. If the forest has a fully developed and maintained road system, small patches of down timber and even scattered, individual trees can be salvaged before decay develops. Often this is the case in Oregon and Washington. In Alaska accessibility varies. Some areas

emain readily accessible throughout a rotation. Others may require xtensive road maintenance or setting up a logging camp which may be mpractical for small timber volumes. The fact that wind damage is a ommon problem in hemlock-spruce forests is an argument for maintaining ain access roads to all parts of an ownership and keeping them available for salvage operations.

If blowdown cannot be removed the first summer, special effort hould be made to get it out before the second. Decay of sapwood can e expected to accelerate with time. If only one salvage entry is lanned and additional blowdown is anticipated, it may be best to ccept some loss of sapwood and wait until the second or third season or salvage. This will permit salvaging additional blowdown that may ccur.

Cost of salvaging blowdown timber is higher than for logging tanding timber (Stumbles 1968, Fraser 1964, Crawford 1968, Binkley 964). Windthrown trees are often criss-crossed (fig. 65). They may e under bending stress, making bucking more dangerous than under ormal conditions. Yarding the logs costs more because of hangups ue to root wads and high stumps. If decay has begun, the defective aterial on the outside and at the ends of logs is necessarily handled

Figure 65.--Salvage of windthrown timber is dangerous and costly. Bent stems are under great stress and, when bucked into logs, may injure loggers. Shrubby Island, Alaska.

throughout the logging operation. Net scale will be considerably below gross scale and costs will be proportionately higher than for sound material. Unexpected changes in logging plans to accommodate salvage operations usually result in increased costs.

Discussion

There are two main periods in the life of a forest when special attention should be given to wind. The first is during establishment of the stand. There are areas where forest yield will be restricted by the wind to the extent that it will be best to forgo timber production and designate the land for another use. In this event, it may not be appropriate to establish a forest at all or perhaps to establish only clumps of timber in sheltered locations. Most such areas are near timberline and the north and west extremities of the hemlock-spruce type. In these and similar areas, the trees should be widely spaced so they will develop under wind stress and build up wind resistance.

The second period requiring special attention begins when decisions must be made about thinning and continues up to and including harvest cutting. If improperly done, thinnings contribute to wind damage and can result in economic loss. The land manager must evaluate the wind hazard and other factors and decide what degree of thinning, if any, is appropriate.

If a thinning regime is to be instituted, it is best to begin early in the life of the stand. When trees develop in dense stands, they become more dependent on their neighbors for protection and, therefore, more vulnerable to damage when their neighbors are removed. Generally on deep soils, careful thinning will improve tree stability; although immediately after thinning, the stand will be more vulnerable than before. Where rooting is restricted and most root extension is lateral, thinning may increase wind exposure more than it improves rooting.

Tree height is of major importance in timing harvest cuttings in areas of wind hazard. Throughout the rotation, the forest manager tries to improve tree stability. But in a way this is a losing battle because height growth continuously erodes tree stability by increasing the length of the lever arm working on the stem and the root system. Tree height is the major variable remaining under control of the forest manager.

If the forest manager has a serious problem with damage from wind, there is a tree height above which wind damage becomes a definite risk. There will be a yield loss if this height is below that needed for an economic rotation. The forest manager must weigh the increased risk of wind damage against the increased return from keeping the stand to its economic rotation age. The decision can range all the way from harvesting when wind first becomes a risk to holding the stand to rotation age regardless of wind.

In the first instance, economic loss is certain because the trees will be cut before maturity. In the second, the loss is harder to predict. It depends on the accuracy of predictions of wind damage. The best alternative probably lies between these extremes. A few feet of height increases the value of the crop, and this is worth incurring

some additional risk of wind damage. The best solution for a particu-ar stand will depend on these and many additional factors, including such items as feasibility of salvage operations and markets for small ogs.

Careful management can minimize wind damage but can never prevent t entirely. No matter how effective the management to minimize wind amage, catastrophic storms can be expected to occasionally disrupt anagement plans. The manager's best defense is to develop flexibility nd to prepare contingent plans for salvage of windthrown timber. ood access to timber stands is a key factor. Management prescriptions ill be most effective in dealing with losses between catastrophes; ut the catastrophic storm must be dealt with and there are lessons to earn from it.

MULTIPLE USE

Timber is a major resource throughout the hemlock-spruce type; ut soil, air, water, range, recreation, esthetics, wildlife, fish, nd minerals are important resources as well. Timber harvesting ffects all resources, and all must be considered in forest management ecisions. Multiple use of resources is practiced to various degrees hroughout the hemlock-spruce type. The degree depends on forest wnership, suitability of the land, and relative demands for various esources. Emphasis on multiple use is strongest on Federal lands here it is required by law. The States of Alaska, Oregon, and Wash-ngton have also enacted legislation concerning multiple use of resources.

Private forest landowners are not legally bound to practice ultiple use to the same extent. However, State and Federal water ollution laws and State laws regulating fish and wildlife require rivate landowners to protect streams and lakes within their properties. aws pertaining to air quality also affect management practices on rivate land. Most owners of large tracts allow the general public ccess to their property for the use and enjoyment of fish, game, or ecreational resources. Esthetics or visual resources are often pro-ected where major highways cross industrial forest lands. So to arious degrees, multiple use is a concern of virtually all forest anagers.

The multiple-use concept does not mean that every use occurs on very acre. Obviously, not all resources are available on each acre or are all uses compatible. Careful inventory of available resources nd of public and private objectives is essential, followed by allocation f land for various uses. In most cases, several uses on the same area r adjacent areas must be reconciled. Planning then is the key to uccessful application of the principle of multiple use. An example f this is the planning process now being done on the Tongass National orest (USDA Forest Service 1977).

The silviculturist may contribute substantially to the planning rocess through knowledge of stand conditions and the capability of he land for tree growth. Once management decisions regarding alloca-ions have been made, the silviculturist can help to prescribe the est cultural treatments from among those known to be biologically ound for use in the hemlock-spruce type.

SILVICULTURAL SYSTEMS

Clearcutting is widely practiced where timber production is the dominant use. Guidelines have been developed; if followed, these guidelines will minimize adverse effects of clearcutting on other land uses. Often the key to mitigating conflicts is simply adequate supervision of timber sales or other management activities. Separation of conflicting land uses can be effective in many cases. Other silvicultural systems could, theoretically, be used to good advantage where clearcutting is incompatible with other land uses; for example, when maintenance or modification of an existing timber stand is desired. Campgrounds, streamside or beach stands, deer winter range, and roadsi stands are examples of situations where a combination of high forest and small openings may be desired. At present in the western hemlock-Sitka spruce type, we have few demonstrations of benefits from alternative silvicultural systems. Silvicultural practices to better integrate land uses should be developed. Examples of important multiple-u considerations in the hemlock-spruce type follow.

WATER AND FISH HABITAT

Water and fish are resources that are especially important in coastal forests (fig. 66). In Alaska especially, forests and waterway

Figure 66.--Fish and timber resources are closely related in the hemlock-spruce forests. A typical stream used by salmon and trout for spawning and rearing. Montana Creek near Juneau, Alaska.

are closely interwoven. In southeast Alaska alone there are 9,000 mi (15 000 km) of coastal shoreline and numerous lakes and streams on the mainland and islands. More than 1,100 streams are estimated to be used by salmon (Schmiege et al. 1974).

Timber management activities must be carried out in a manner that will assure protection of water quality and fish habitat. Research has shown that damage can occur in many ways but that damage need not occur.

One of the most obvious ways logging may affect streams adversely is from the introduction of logging residue. Logs, limbs, and tops of trees can block passage or occupy space in rearing areas that could otherwise be used by fish (Meehan 1974). Small debris--such as bark, twigs, and leaves--can reduce food supplies for rearing fish by filling the gravel interstices and interfering with stream invertebrates (Ponce 1974) (fig. 67). Logging debris may reduce water quality by blocking water flow and reducing dissolved oxygen supplies (Narver 1971, Reed and Elliott 1972).

Figure 67.--Small residues (such as bark and wood chips, twigs, and needles) damage fish habitat in spawning and rearing streams. Seal Bay, Chichagof Island, Alaska. (Photo, courtesy Alaska Department of Fish and Game).

Above the high water marks, burning of logging residues may ffect water quality if the fire is hot enough to consume surface rganic material. Additional mineral soil is exposed, and soil rapped by residues may be released. Generally, erosion from pre-cribed burning is not a serious problem in coastal areas because the ercentage of exposed soil is not greatly increased (Morris 1970). lso, developing vegetation may stabilize the soil before it reaches a tream. In special situations, however, burning may contribute to

stream sedimentation; this possibility should be evaluated when plans for managing residues are developed.

Burning may reduce the infiltration rate of water into the soil (Austin and Baisinger 1955), and this temporarily tends to increase peak overland flows. To the extent live vegetation is damaged or killed by fire, transpiration is reduced and more soil water is available for streamflow.

Summer stream temperatures increase when streamside vegetation is removed. For example, Meehan et al. (1969) found that in Alaska after complete clearcutting of about 7 mi (11 km) of main stream in Harris River and 5 mi (8 km) of Maybeso Creek, maximum stream temperatures rose from 4°F (2°C) to 9°F (5°C), for the months of April through September. The temperature increase depends on such factors as streamflow, length of channel exposed by clearcutting, groundwater, and general climatic conditions. Temperatures increase more farther south, and a method of predicting the effect of clearcutting on stream temperature has been developed (Brown and Krygier 1970).

Water temperature in small streams may increase dramatically during burning of residues. A severe instance occurred in Needle Branch, a V-shaped valley with steep slopes, on the Oregon coast. Stream temperature rose from 55°F (13°C) to 82°F (28°C) during slash burning. This increase was enough to kill many juvenile coho salmon, cutthroat trout, and sculpin. The population of cutthroat trout was severely affected for a long period; the population levels of other fish returned to normal within 2 years (Hall and Lantz 1969).

Chemistry of surface waters may be altered by timber management practices, such as clearcutting, burning, fertilization, and the use of pesticides. Clearcutting has been shown to increase soil temperature in the hemlock-spruce type (Gregory 1956). Such increases are known to increase biological decomposition rates and thereby release nutrients which may enter stream water. For example, a study in Alaska showed some significant changes in soil and surface waters associated with clearcutting (Schmiege et al. 1974), as indicated in table 8.

Table 8--Nutrient content of soils and surface water before and after timber harvest[1/]

Nutrient	Surface water (creeks)		Soil water: Tokeen soils, well drained		Soil water: Wadleigh soils, somewhat poorly drained	
	Timbered	Clearcut	Timbered	Clearcut	Timbered	Clearcut
	Milligrams per liter					
Nitrate	0.062	0.094*	0.055	0.116*	0.067	0.195*
Phosphate	.86	1.04	1.02	.914	.76	.915
Iron	.07	.15*	.1	.07	.1	1.30*
Calcium	1.72	1.45	1.30	2.23*	1.38	2.35*
Magnesium	.185	.24	.16	.34*	.20	.17
Potassium	.52	.85*	.35	.70*	1.68	2.65*
Sodium	1.12	1.16	1.60	2.26*	1.15	1.15
Organic carbon	4.8	6.3	7.0	12.5	7.0	30.0*

*Indicates that differences between samples from clearcut and timbered areas are probably real, judging by the magnitude of difference and variation between duplicate samples. Analysis by Federal Water Quality Laboratory, Fairbanks, Alaska.

[1/] USDA Forest Service Environmental Statement, Ketchikan Pulp Company Timber Sale 1974-1979 Operating Period. On file, USDA Forest Service, Juneau, Alaska.

Organic compounds may be leached from logs that are stored or transported in water. Pease (1974) found high concentrations of these chemicals at log raft storage sites in Alaska. Such leachates can be toxic to salmon fry. Bark and other debris from logs can form an impervious bottom layer in bays and estuaries where logs are stored (Ellis 1970), affecting animals such as crabs and clams.

Chemicals such as pesticides and fertilizers may be introduced into streams from silvicultural operations (Norris and Moore 1971, Meehan 1974). Different degrees of toxicity to fish by various formulations of the same pesticide have been demonstrated (Sears and Meehan 1971). Meehan (1974) pointed out that the behavior of each chemical formulation and the effects on aquatic life must be known before widespread application.

Increased sedimentation reduces water quality and degrades fish habitat. Suspended sediment directly reduces water quality and may damage fish and fish habitat by increasing turbidity, thus hampering access to food by fish that feed by sight (Phillips 1971). More important though is damage from sediment deposited in spawning gravels. This sediment can block free flow of oxygen-carrying water and fill gravel interstices and thereby damage eggs or alevins (Cooper 1965, McNeil 1966, Vaux 1962). Sedimentation may be caused by logging and roadbuilding; roadbuilding is usually the greater contributor (Swanston 1971).

In Alaska, mass wasting or landslides are common in unlogged watersheds and contribute to stream sedimentation. In some cases the frequency of mass movement has been shown to increase greatly after clearcutting. The problem is discussed in more detail on page 101.

It is now recognized that from an economic standpoint, fisheries values can often exceed the value of timber within 100 ft (30 m) of a stream (Sadler 1970). Thus the protection of streams through silvicultural management of streamside vegetation is receiving greater attention.

In British Columbia narrow strips of vegetation, commonly referred to as leave strips or fringe strips, are now often left along streams for protection where clearcutting is done (Burns 1970, McMynn 1970). Leave strips are subject to damage by wind, and forest managers have been reluctant to include them in management plans. Efforts are being made to understand factors associated with blowdown of streamside leave strips and to provide guidelines that will help to make possible the design of more stable leave strips (Moore 1977).

Improved management prescriptions designed to protect the streams and still allow harvest of valuable timber from streamside stands are needed.

WILDLIFE

Hemlock-spruce forests are habitats for many species of wildlife. Wild mammals may, in some cases, damage trees and stands, as was noted in a previous section; but the limited damage that occurs is usually overshadowed by the benefits derived from wildlife. Wildlife species

provide recreation and enjoyment to people, and some animals are used as food. Trapping of fur bearers is an important source of income for a few people. Animals often serve as vital links in maintaining a productive forest ecosystem.

Logging drastically changes the forest ecosystem and so may cause changes in composition and relative abundance of wildlife. Studies elsewhere show that some species of wildlife respond favorably to logging, whereas others suffer because of loss of suitable habitat. If a management plan includes some predetermined mix and density of animal species, it must allow for the habitat needed.

Management of wildlife is the responsibility of each State. The management of wildlife habitat, however, is largely the responsibility of forest landowners and managers. Only through cooperation can good wildlife management be assured.

Big game animals are especially important from the standpoint of hunting and general esthetic enjoyment. Many big game species occur within the hemlock-spruce type. Deer and black bear are found throughout. Elk occur in Oregon and Washington but in Alaska are found only outside the hemlock-spruce type. Brown bear, wolf, mountain goat, and moose are found within the hemlock-spruce type in Alaska.

In portions of the hemlock-spruce type toward the south where winter snow is light, clearcutting, burning, or otherwise opening up of old-growth stands may improve conditions for deer (Cowan 1945, Mitchell 1950). Toward the north, however, where snow is the major factor limiting populations, the low-elevation, old-growth forest is critical for survival of deer during periods of severe weather (USDA Forest Service 1977, Alaska Department of Fish and Game 1977). Clearcutting may reduce the amount of suitable deer habitat. Summer forage may be increased for several years after clearcutting as forbs, grass and woody plants proliferate, but summer forage is usually more than adequate without logging. During the winter, forage on clearcuts is largely unavailable to deer because of deep snow (Jones 1975, Merriam 1971).

In southeast Alaska, most cutover areas regenerate quickly to dense stands of hemlock and spruce and soon shade out forage plants. Such stands may offer cover for deer but provide little available forage. Within the rotation period, the forage supply for deer may not regain the levels that occur under old-growth forests.

Periodic thinning and the use of silvicultural systems other than clearcutting in some areas could conceivably maintain or improve deer habitat, although this is yet to be demonstrated. Quantitative area-by-area information is needed on the habitat requirements of deer and on the ability of various forest stands to supply those requirements under natural conditions and under management.

Black bear may benefit from clearcutting because of increased food supplies. During much of the year, berries and other plant material make up a large part of a bear's diet; and many edible plants are among the early pioneers on cutover land (Erickson 1965) (fig. 68).

Brown bear are found in the hemlock-spruce forests of Alaska. Tidal flats and alpine areas are important feeding areas during some

Figure 68.--Bear depend on berries and other plant material for food during much of the year when salmon are not available. A brown bear on the Pack Creek, Admiralty Island, Alaska.

easons, and salmon are an important part of the bear's diet during he fall. Hemlock-spruce forests offer cover for brown bear, and ost feeding on tidal flats and beaches is along a forested fringe Perensovich 1964).

Logging is not expected to have a direct effect on brown bear opulations, but the presence of camps and people may cause changes. o far there appears to be no general shift of bear populations from resent cutting areas.

Proper garbage disposal, so as not to attract bears, would eliminate uch of the killing of "nuisance" animals. Around permanent or seasonal ommunities, brown bears are often eliminated to protect people or proprty. Fishermen often shoot bears because they are believed to be a ompeting predator (Meehan 1974).

Bald eagles are plentiful in southeast Alaska, with an estimated reeding population in excess of 8,000 birds (King et al. 1972). Nests re mainly built in old-growth trees, nearly always within several undred feet of shorelines (Meehan 1974). Bald eagles are endangered pecies in most areas of the United States and receive special protection n Alaska. Nesting sites are carefully protected, and no timber utting can be done within a 5-chain (100-m) radius of a nest tree USDA Forest Service, Alaska Region).

Other species of game and nongame animals and birds occur within hemlock-spruce forests, but in most cases little is known about their habitat needs. This is especially true for nongame species (fig. 69). The recent increase in environmental awareness and dramatic changes in patterns of wildlife-related recreation are doing a great deal to change this picture (DeGraaf 1978). The forest manager must be ready to modify practices when necessary in the light of new information.

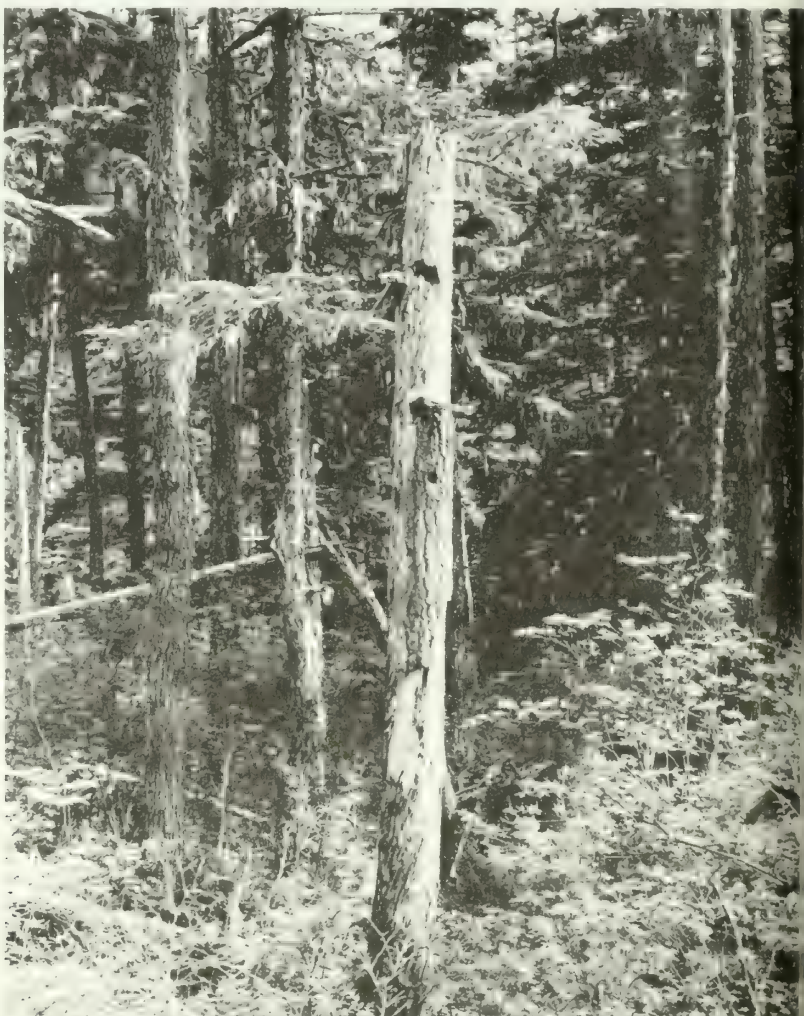

Figure 69.--Snags in old-growth stands provide nesting trees for birds. Tee Harbor, Alaska.

RECREATION AND ESTHETICS

Recreation and esthetic enjoyment are long-established values of forest land. Along with recreational activities, concern about the quality of the visual environment has been increasing. Because of this concern on the National Forests, it has become appropriate to establish the "visual landscape" as a basic resource, to be "treated as an essential part of and receive equal consideration with the other basic resources of the land."[25/]

[25/] Forest Service Manual Chapter 2380 - Landscape management. FSM 2/77 Amend. 74. U.S. Gov. Print. Off. 1977-241-420/FS-25.

The emphasis on visual quality has led to the incorporation of landscape management as an integral part of land management on the National Forests. The basic concepts of landscape management and methods of practical application have been described (USDA Forest Service 1973, 1974). In general, the objectives in relation to timber management are to retain or enhance scenic quality and to make human activities less obtrusive.

Landscape management and timber management are inseparable in the hemlock-spruce type. The combination of dense commercial forests reaching down to the sea, water-oriented recreation and esthetics, and clearcutting as the basic silvicultural system means that the landscape architect and timber management specialist must work together closely to maintain acceptable visual standards. Clearcutting units can be shaped and placed to be less obtrusive. Cutting boundaries, however, must be windfirm to avoid loss of timber around edges.

With recreational use of coastal forests mostly water oriented, distant views of cutover areas are particularly important (fig. 70). Color and general appearance are major factors. During the 1st year after clearcutting, logging debris, stumps, and the organic duff layer are brown, contrasting with the green of surrounding timber. From the 1st to 4th year, green plants cover the ground. Stumps, logs, and tops bleach to a gray. The green plants blend with surrounding timber, and the major contrast is between adjacent ground vegetation and the gray of the residues. From 5 to 8 years after clearcutting, residues become covered by ground vegetation and major contrasts disappear. A new hemlock-spruce forest canopy usually closes over the area 15 to 20 years after clearcutting.

Figure 70.--The visual effects of clearcutting are evident along the inside passage in Alaska.

Residues contribute substantially to an impression of forest devastation after clearcutting. Although public reaction to timber harvesting usually focuses more on the loss of tree cover than on the logging debris, the presence of large amounts of residue is taken by many people as evidence of forest devastation (Wagar 1974) and as a waste of wood fiber. Direct contact with forest residue is of greatest concern in areas of high public use, usually near roads and campgrounds where berrypicking and hunting are important.

Snags are a special component of forest residue, especially important in old-growth forests. The esthetic value of snags is, of course, subjective and will be judged differently by different people (fig. 71). Snags often have value as nesting sites (Scott et al. 1977) but may also interfere with timber management activities. Conflicts, based on concern for safety and on concern for various resources, may develop over the disposition of snags. Blanket rules governing disposition of snags on all cutover areas are not desirable. Ideally, a compromise solution for retention of snags on each cutting unit should be worked out by various management specialists.

Figure 71.--Eight years after logging, most residues are hidden by conifers but snags remain in view. The esthetic value of snags varies by their numbers and distribution and by the individual tastes of viewers. Maybeso Valley, Alaska.

The adverse esthetic effects of logging residue may be directly reduced by rearranging or reducing the amount of residue left after logging; indirectly by separating people from timber harvest operations

and perhaps by education to show the public why residues are created and some of their positive benefits. Some combination of the following actions would improve postharvest esthetics in the hemlock-spruce type.

1. Improve utilization. Better utilization would directly eliminate much of the problem, especially that of large residues.

2. Clean up foreground areas along travel routes. The condition of the foreground has a great effect on one's perception of an entire cutover unit. Also, the greatest public use of cutover areas is adjacent to roads. Yarding and burning unutilized material has application in foreground cleanup.

3. Lay out cutting units, whenever possible, so they are screened from public view. Leaving uncut strips along roadways or waterways and placing cutting units to blend with topography helps reduce adverse esthetic effects. When necessary to cut along travel routes, small cutting units are less objectionable than large ones.

4. Treat residue. Broadcast burning or piling and burning substantially reduces the amount of residue and greatly improves access. Charring of remaining debris causes it to blend in better with the surrounding soil surface and thereby reduces its visibility. Clearcuts revegetate quickly, providing a contrast between the green foliage and burned residue.

5. Educate. The public needs to be better informed about residue management. People will better understand the reality of woods operations if they know the roles played by forest residues in nutrient cycling and forest regeneration and understand the economics of wood utilization.

Residues created by precommercial and commercial thinning and by shelterwood cutting also have esthetic effects but less drastic than those associated with clearcutting. Volumes are less, sizes smaller, and much of the residue is screened from view by the residual stand. Residues from precommercial thinning substantially hamper travel through an area until thinned stems have settled to the ground.

In some situations, clearcutting may be incompatible with landscape management objectives. Some form of partial cutting could allow timber removal while retaining the forest appearance. Silvicultural systems used in connection with partial cutting must be compatible with ecological characteristics of the tree species involved, and timber extraction must be economically feasible.

AIR QUALITY

Air is an essential resource but one usually taken for granted. Pure air is essential to enjoyment everywhere, and only when it becomes polluted do we become aware of the degradation of this resource.

Within the hemlock-spruce type, pure air is abundant, as most prevailing winds are onshore. Where air pollution exists, it is localized around urban or industrial sites. Timber management activities may contribute to local problems. Dust and fumes--along with the

noise of trucks, heavy equipment, and chain saws--are common features of logging activity. Fortunately, these activities are usually locat far from urban centers.

Smoke from prescribed burning of forest residues is the primary source of air pollution caused by timber management activities. Effects of prescribed fire on air quality are summarized by Hall (197 He concluded that, "In general, the only penalty inflicted upon the environment by prescribed burning is a small and temporary decrease i visibility." Burning of forest residues does not produce the sulfur oxides common to combustion of coal and oil. Production of nitrogen oxides is rare. Carbon monoxide and carbon dioxide concentrations were measured near the perimeter of an experimental burn of Douglas-f residue in western Washington, and high concentrations at the site decreased rapidly to normal in both horizontal and vertical direction (Fritschen et al. 1970; Murphy et al. 1970a, 1970b). Hydrocarbons produced by burning residues are similar to or identical with natural products always present in the environment. Only small traces of low-molecular-weight, photochemically active compounds are produced (Hall 1972).

Close to a prescribed fire, dense smoke may be unpleasant from the standpoint of odor and lung or eye irritation. Locally, it can obstruct visibility to the point of being a traffic hazard. But mainly, smoke and haze obstruct distant views and thereby decrease visibility and enjoyment of the outdoors. Objections to prescribed burning are strongest in urban areas. Problems can be reduced by developing smoke management systems that will keep smoke out of sensitive areas. Such a system requires knowledge of smoke behavior and cooperation between public and private forestry agencies (Cramer and Graham 1971).

The land manager often must decide whether it is better to reduce fire hazard by prescribed burning, with reasonable management of smoke, or to leave the hazard and hope it will never burn. Leavin it runs the risk of wildfire with much greater smoke emission and the possibility that smoke will drift over urban areas. Prescribed fires can be set when airflow will disperse smoke and carry it away from urban areas, when a hot convection column will carry smoke aloft, and when fuel is dry enough to burn with little smoke (Cramer and Graham 17 The latter is difficult in hemlock-spruce forests compared with drier inland forests. Prolonged smoldering of slash piles produces a lot o smoke which, without strong convection currents, tends to flow at ground level. A mixture of soil in the slash aggravates this problem.

RANGE

Grazing by domestic livestock is virtually nonexistent within hemlock-spruce forests. Stands tend to be dense, with little availab forage; terrain is often steep; and climatic conditions are unsuitabl In Oregon and Washington some livestock are grazed on cleared land along streams. In coastal Alaska the only significant grasslands are on tidal flats, but use of these lands for domestic animals has not proved feasible. Grazing by wildlife will continue to be the major use of the small amount of rangeland within the hemlock-spruce type.

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APPENDIX

Common and Scientific Names	Plants
Alaska-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach
alder, red	*Alnus rubra* Bong.
alder, Sitka	*Alnus sinuata* (Reg.) Rydb.
alder, thinleaf	*Alnus tenuifolia* Nutt.
blueberry, Alaska	*Vaccinium alaskense* Howell
blueberry, early	*Vaccinium ovalifolium* Sm.
bracken	*Pteridium aquilinum* (L.) Kuhn
bunchberry	*Cornus canadensis* L.
cottonwood, black	*Populus trichocarpa* Torr. & Gray
currant, stink	*Ribes bracteosum* Dougl.
currant, trailing black	*Ribes laxiflorum* Pursh
deerberry	*Maianthemum dilatatum* (Wood) Nels. & Macbr.
deerfern	*Blechnum spicant* (L.) Roth
devilsclub	*Oplopanax horridus* (Sm.) Miq.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
dwarf mistletoe, hemlock	*Arceuthobium tsugense* (Rosend.) G. N. Jones
elder, Pacific red	*Sambucus callicarpa* Greene
fir, Pacific silver	*Abies amabilis* (Dougl.) Forbes
fir, subalpine	*Abies lasiocarpa* (Hook.) Nutt.
five-leaf bramble	*Rubus pedatus* J. E. Smith
hemlock, mountain	*Tsuga mertensiana* (Bong.) Carr.
hemlock, western	*Tsuga heterophylla* (Raf.) Sarg.
huckleberry, evergreen	*Vaccinium ovatum* Pursh
huckleberry, red	*Vaccinium parvifolium* Sm.
lace flower	*Tiarella trifoliata* L.
ladyfern	*Athyrium filix-femina* (L.) Roth
maple, bigleaf	*Acer macrophyllum* Pursh
maple, Douglas	*Acer glabrum* Torr. var. *douglasii* (Hook.) Dipp.
maple, vine	*Acer circinatum* Pursh
menziesia, rusty	*Menziesia ferruginea* Sm.
Oregongrape	*Berberis nervosa* Pursh
oxalis, Oregon	*Oxalis oregana* Nutt. ex T. & G.
pine, shore	*Pinus contorta* Dougl. var. *contorta*
pine, western white	*Pinus monticola* Dougl.
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A. Murr.) Parl.
redcedar, western	*Thuja plicata* Donn
redwood, coast	*Sequoia sempervirens* (D. Don) Endl.
rhododendron, Pacific	*Rhododendron macrophyllum* G. Don
salal	*Gaultheria shallon* Pursh
salmonberry	*Rubus spectabilis* Pursh
saxifrage, western golden	*Chrysosplenium glechomaefolium* Nutt.
skunk cabbage	*Lysichiton americanum* Hult. & St. John
Smith's fairybells	*Disporum smithii* (Hook.) Piper
snow dewberry	*Rubus nivalis* Dougl. ex Hook.
spreading woodfern	*Dryopteris dilatata* (Hoffm.) Gray
spruce, Lutz	*Picea X lutzii* Little
spruce, Sitka	*Picea sitchensis* (Bong.) Carr.
spruce, white	*Picea glauca* (Moench) Voss
swordfern	*Polystichum munitum* (Kaulf.) Presl
thimbleberry, western	*Rubus parviflorus* Nutt.
twisted stalk, clasping	*Streptopus amplexifolius* (L.) DC.
violet, evergreen	*Viola sempervirens* Greene

violet, stream	*Viola glabella* Nutt.
waterhemlock, western	*Cicuta douglasii* (DC.) Coult. & Rose
water parsley	*Oenanthe sarmentosa* Presl ex. D.C.
western springbeauty	*Montia sibirica* (L.) How.
willows	*Salix* sp.
woodfern, mountain	*Dryopteris austraica* (Jacq.) Woynar ex Schinz and Thell.

Insects

aphid, spruce	*Elatobium abietinum* (Walker)
beetle, striped ambrosia	*Trypodendron lineatum* (Olivier)
beetle, bark	*Dendroctonus* spp.
beetle, spruce	*Dendroctonus rufipennis* (Kirby)
budworm, western black-headed	*Acleris gloverana* (Walsingham)
budworm, spruce	*Choristoneura fumiferana* (Clemens)
looper, saddle-backed	*Ectropis crepuscularia* (Denis and Schiffermüller)
looper, western hemlock	*Lambdina fiscellaria lugubrosa* (Hulst)
sawfly, hemlock	*Neodiprion tsugae* Middleton
weevil, white pine	*Pissodes strobi* (Peck)

Fungi[1/]

annosus root rot	*Fomes annosus* (Fr.) Cke.
artist's conk	*Fomes applanatus* (Pers.) Gill. = [*Ganoderma applanatum* (Pers. ex Wallr.)]
red belt fungus	*Fomes pinicola* (Schwartz ex Fr.) Cke.
red ring rot	*Fomes pini* [(Brot.) Fr.] Karst.
shoe string fungus	*Armillaria mellea* (Vahl ex Fr.) Kumm = [*Armillariella mellea* (Vahl ex Fr.) Karst.]
sirococcus shoot blight	*Sirococcus strobilinus* (Desm.)
soft spongy white rot	*Ganoderma oregonense* Murr.
white heart rot	*Fomes robustus* Karst.
white ring rot	*Poria albipellucida* Baxter [*Poria rivulosa* (Berk. & Curt.) Cke.]
white trunk rot	*Fomes hartigii* (Allesch.) Sacc. and Trav. [*Fomes robustus* Karst.]
yellow laminate root rot	*Poria weirii* (Murr.) Murr. = [*Phellinus weirii* (Murr.) Gilbertson]

Mammals, Birds, Fish

bear, black	*Ursus americanus* Pallas
bear, brown	*Ursus arctos horribilis* Ord.
beaver, bank	*Castor canadensis* Kuhl
beaver, mountain	*Aplodontia rufa* (Rafinesque)
deer, Columbian black-tailed	*Odocoileus hemionus columbianus* (Richardson)
deer, Sitka black-tailed	*Odocoileus hemionus sitkensis* Merriam
eagle, bald	*Haliaeetus leucocephalus alascánus* Townsend
elk, Roosevelt	*Cervus elaphus roosevelti* Merriam
goat, mountain	*Oreamnos americanus* (Blainville)
hare, snowshoe	*Lepus americanus* Erxleben
rabbit, brush	*Sylvilagus backmani* (Waterhouse)
salmon, coho	*Oncorhynchus kisutch* (Walbaum)
sapsucker, red-breasted	*Sphyrapicus varius ruber* (Gmelin)
squirrel, red	*Tamiasciurus hudsonicus* (Erxleben)
trout, cutthroat	*Salmo clarki* Richardson
wolf	*Canis lupus* Linnaeus

[1/] Nomenclature follows Shaw (1973).

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.

2. Developing and evaluating alternative methods and levels of resource management.

3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

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